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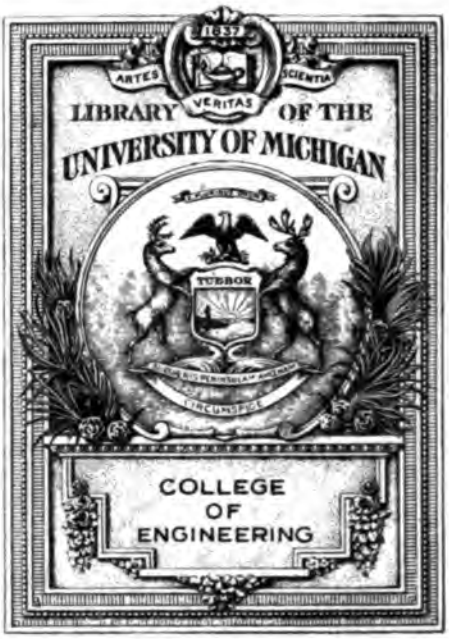
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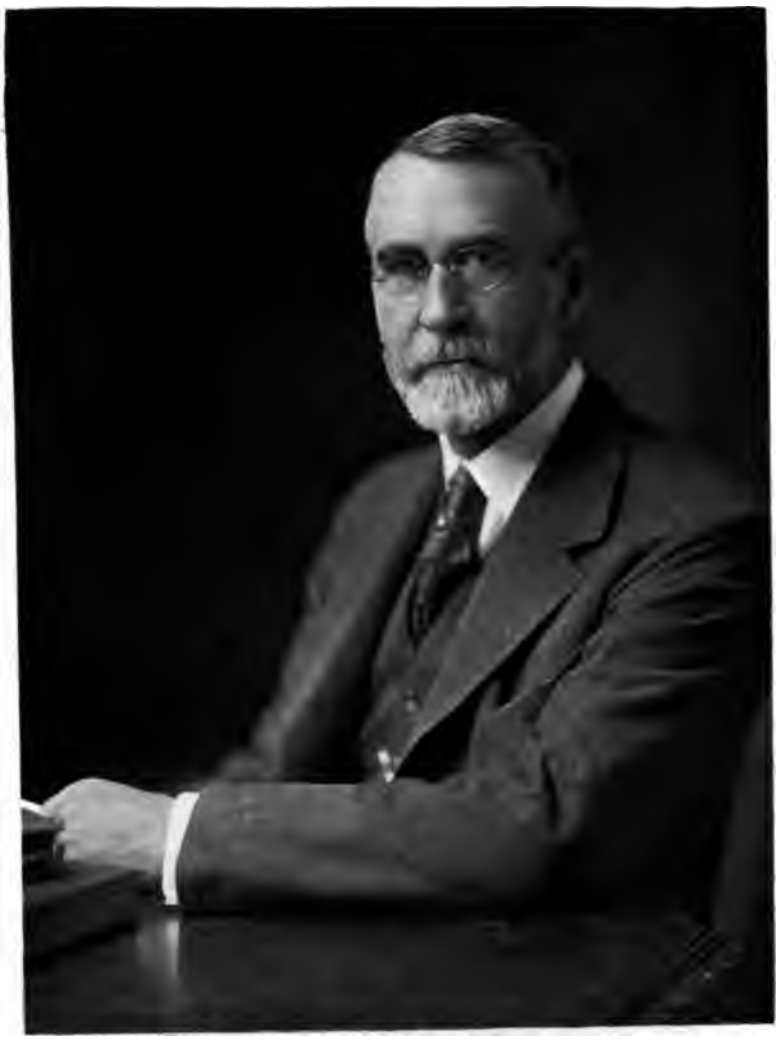

Charles T. Main

PRESIDENT 1919

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

THE AMERICAN SOCIETY OF
MECHANICAL ENGINEERS

TRANSACTIONS

VOLUME 40

WORCESTER MEETING
NEW YORK MEETING
1918

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SUMMARY OF MEMBERSHIP BY RESIDENCE

United States

Alabama	73	Montana	6
Alaska	1	Nebraska	17
Arizona	19	Nevada	4
Arkansas	8	New Hampshire	27
California	269	New Jersey	576
Canal Zone	5	New Mexico	12
Colorado	43	New York	2311
Connecticut	498	North Carolina	26
Delaware	85	North Dakota	2
District of Columbia	359	Ohio	603
Florida	32	Oklahoma	40
Georgia	58	Oregon	21
Guam	1	Pennsylvania	1172
Hawaii	16	Philippine Islands	13
Idaho	4	Porto Rico	7
Illinois	618	Rhode Island	100
Indiana	151	South Carolina	16
Iowa	32	South Dakota	2
Kansas	39	Tennessee	51
Kentucky	39	Texas	83
Louisiana	49	Utah	16
Maine	27	Vermont	28
Maryland	164	Virginia	117
Massachusetts	799	Washington	53
Michigan	316	West Virginia	29
Minnesota	104	Wisconsin	170
Mississippi	11	Wyoming	5
Missouri	149		
		Total	9476

Foreign Countries

Africa	11	Italy	4
Australia	12	Japan	16
Austria	2	Mexico	6
Belgium	1	Norway	3
British West Indies	1	Roumania	1
Canada	154	Russia	8
Central America	2	Scotland	4
China	12	Singapore Straits	1
Cuba	32	South America	37
Denmark	2	Spain	2
Java	1	Sweden	8
England	71	Switzerland	3
Finland	2	Turkey	1
France	278	Republic of Domingo	1
Germany	18	Jamaica	1
Holland	1	West Indies	1
India	9		
		Total	706

Membership in United States	9476
Membership in Foreign Countries	706
Present address unknown	7
Total Membership	10189

Membership by Grades

Honorary Members	13
Members	5527
Associate-Members	1702
Associates	585
Juniors	2274
Life Members	84
Life Associates	3
Life Juniors	1
Total Membership	10189

TRANSACTIONS

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOLUME 40 — 1918

THIS volume comprises a record of the proceedings of The American Society of Mechanical Engineers for the year 1918, and in it will be found papers and addresses given at the Spring and Annual Meetings of the Society, discussion thereon, the extended symposium on The Economical Use of Fuel presented at the Spring Meeting, and also a number of papers contributed by the Local Sections.

In selecting the material published in the present volume, the intention has been to include all of the papers possessing permanent reference value. A number dealing more particularly with industrial and economic matters connected with war activities and whose interest and value depended to a great extent upon the timeliness of their presentation, have been omitted. These, however, are listed in the index, where reference is made to the issues of THE JOURNAL in which they appeared and in which published form they are available for consultation.

CHARLES THOMAS MAIN

Charles Thomas Main was born in Marblehead, Mass., on February 16, 1856. He attended the public schools in that town and was graduated from the Massachusetts Institute of Technology in the class of 1876 with the degree of S.B. in the department of mechanical engineering.

He remained at the Institute as an assistant in the department of mechanical engineering for three years after graduation.

In the fall of 1879 he went to Manchester Mills, Manchester, N. H., as draftsman. From there, on January 1, 1881, he went to Lawrence, Mass., as engineer for the Lower Pacific Mills. In March

1886 he was made assistant superintendent of the mill, and about a year later superintendent, which position he held until 1892, meanwhile also giving his attention to the engineering work. During this period of eleven years he had charge of the reorganization and the rebuilding of a large portion of the plant, and for something over five years supervision of its operation.

About this time Mr. Main decided that he preferred to follow engineering rather than administrative work and resigned his office at the Pacific Mills. After one year in Providence, R. I., spent in engineering and mill work, he formed an association with Mr. F. W. Dean and conducted a business under the name of Dean & Main, devoted largely in the early days to textile-mill work, but gradually broadening so as to include other industrial plants. This association existed from January 1893 to January 1907, when it was dissolved. Since that time he has conducted an engineering business under the name of Chas. T. Main.

During the period from 1893 to the present time a large number of industrial plants have been designed and constructed under his direction and many others reorganized, the steam engineering for industrial plants developing into steam-power-plant work, and the water-power work into hydroelectric developments.

Among the largest undertakings in the industrial plants are the Wood Worsted and Ayer Mills in Lawrence, Mass., and in hydroelectric work four developments for the Montana Power Company, aggregating about 250,000 hp.

He has acted as consulting engineer on many projects and as expert witness or referee in many important cases and has placed valuations on many industrial plants for various purposes.

He was elected to membership in The American Society of Mechanical Engineers in 1885 and was a manager from 1914 to 1917. He is also a member of the American Society of Civil Engineers, the American Institute of Consulting Engineers, the Boston Society of Civil Engineers (past-president), and of other technical societies; is president of the Engineers' Club in Boston, and is a life member of the Corporation of the Massachusetts Institute of Technology.

He has written several papers on engineering subjects, some of which have been presented at meetings of the Society.

Mr. Main has been interested for many years in public affairs and has served in several municipal offices for the purpose of advancing the idea of good government and doing his share of public work.

No. 1635

MEETINGS JANUARY–JUNE

MEETINGS OF SECTIONS

EIGHTY–TWO meetings were held by the twenty organized Sections of the Society and the Providence Engineering Society, an affiliated body, during the first six months of the year. Twenty-two of these meetings were arranged jointly with one or more local technical organizations or branches of other national engineering societies in fifteen different centers. President Main and Secretary Rice visited seven of the Sections, and addressed meetings on various dates. A number of the papers of more general interest which were presented at these meetings were published in THE JOURNAL during 1918.

ATLANTA

February 12: Chairman Oscar Elsas gave a report of the Conference of Sections delegates at the Annual Meeting of the Society.

April 9: Address on The Effect Upon Fuel Economy of Different Arrangements of Baffles in Boiler Tubes, W. G. Eager. Abstract published in THE JOURNAL, September 1918.

BALTIMORE

January 10: Joint meeting with the Engineers' Club and the various associations of stationary engineers, to discuss the subject of Fuel Saving. Charles H. Bromley delivered the main address on How to Get the Most Out of Coal.

January 29: Henry Adams presented a paper on Some Engineering Experiences.

March 12: Subject: Canning of Foods. Papers by J. H. Shrader on Economies in Manufacturing in the Canning Industry, published in THE JOURNAL, August 1918; by Julian C. Smallwood on Investigation of the Uses of Steam in the Canning Industry, published in this volume of TRANSACTIONS and in THE JOURNAL, May 1918; and by J. C. Taliaferro on The Filling and Closing of the Modern Can.

May 22: Election of officers. Address, illustrated by lantern slides, on Hog Island, the Greatest Shipyard in the World, by W. H. Blood, Jr.

BIRMINGHAM

February 22: Joint meeting with Alabama Technical Society, at which C. B. Davis delivered a paper on Fuel Conservation and Increased Production.

March 21: J. A. Sirnit gave a talk on Water and Fuel Equipment, Warrior River Reserve Station.

April 25: Paper on The Gas-Producing Plant of the American Cast-Iron Pipe Company, by J. W. Moore.

May 16: Addresses by Chairman J. H. Klinck on achievements of the Section during the past year; Major F. H. Wagner, O.O.R.C, U.S.A., on some of the problems in connection with the fixation of nitrogen; Secretary Calvin W. Rice on various timely topics.

BOSTON

January 22: Reception-smoker tendered to President Charles T. Main, preceded by a dinner. Short addresses by Professor Whipple, John R. Freeman, Desmond Fitzgerald, Lionel S. Marks, Dugald C. Jackson, H. S. Hale, Calvin W. Rice and W. H. Balch.

February 5: Joint meeting with Boston Section, American Institute of Electrical Engineers. Paper on The Modern Trend of Education, Walter I. Slichter.

March 16: Address on Man Power, J. Parke Channing. Abstract published in THE JOURNAL, June 1918.

April 30: Joint meeting with Boston Society of Civil Engineers and the American Institute of Electrical Engineers. Illustrated address on Hog Island, W. H. Blood, Jr.; address by Alfred D. Flinn, Secretary of the Engineering Council, on the progress and aims of the Engineering Council; short addresses on subjects of the day by Major-General H. F. Hodges, in command of Camp Devens, and Mayor Andrew J. Peters, of Boston. Motion pictures were shown by H. O. Westendarp illustrating the adaptability of a new rudder he had perfected.

May 29: Annual meeting at which officers were elected for ensuing year. Addresses by President Charles T. Main and Past-President Ira N. Hollis; Dr. Charles H. Eaton delivered an address on America at the Gateway of Destiny.

BUFFALO

January 9: L. C. Loewenstein gave a paper on The Widening Field of the Steam Turbine as a Prime Mover.

February 6: Meeting of Buffalo Engineering Society and Buffalo Section of the Society of Automotive Engineers. Paper on Electric Storage Batteries, C. C. Carpenter.

February 13: Illustrated lecture on The Development of Concrete Barge and Ship Construction, J. E. Freeman. Abstract published in THE JOURNAL, April 1918.

February 20: Discussion of Manual and Technical Training, F. E. Cardullo.

March 13: Address by J. A. Johnson on The Hydroelectric Power Problem.

March 27: Dexter S. Kimball delivered a lecture on Water Powers of the Pacific Coast, illustrated with lantern slides.

April 3: Illustrated lecture: The Manufacture of Wrought-Iron Pipe, N. Boland.

April 10: The Recent Development of Propelling Machinery for War and Merchant Ships, Eskil Berg.

April 24: Lecture on Ball Bearings, Their Design, Manufacture and Application, S. W. Gurney.

May 1: Reports of officers and committees, and election of officers for coming year.

CHICAGO

March 1: Subject: The Coal Situation. Discussed by Joseph Harrington and H. H. Stoek.

April 22: Joint meeting with Chicago Section of American Institute of Electrical Engineers and Mechanical and Electrical Sections of the Western Society of Engineers. Paper: The Automobile Plant, by C. F. Kettering.

May 24: Lecture on The Mayfair Pumping Station, John E. Ericson.

June 17: Joint meeting with Western Society of Engineers and Chicago Section of American Institute of Electrical Engineers. Paper: Advantages of High Pressure and Superheat as Affecting Steam-Plant Efficiency, Eskil Berg. Published in this volume of TRANSACTIONS and in THE JOURNAL, September 1918.

CINCINNATI

March 21: Joint meeting with Engineers' Club of Cincinnati, afternoon and evening sessions, with papers on Shop Kinks, Henry Ritter; The Economic Use of Coal by Communities, John T. Faig, illustrated with lantern slides; The Training of Women for Industry, C. U. Carpenter.

May 11: Address by Secretary Calvin W. Rice on Various Activities of the A.S.M.E.

CONNECTICUT

Bridgeport Branch

April 24: Spring meeting, with afternoon and evening sessions. Afternoon: General get-together meeting. Evening: Patriotic address by Judge Pullman; other addresses by Clinton E. Woods on Factory Accounting as a Bill for Controlling Production; Harry E. Harris on Facilitation of War Production by Practicable Manufacturing Allowances; and Wm. R. Webster on Intelligent Specifications and Inspection as a Factor in Production Increase.

Hartford Branch

February 12: Paper on the Functioning and Production of Automatic Fire Arms, B. M. W. Hanson, assisted by Fred T. Moore, who gave a talk on the functioning of the Vickers gun.

May 13: Election of officers for ensuing year, followed by a talk on Submarines by P. B. Brill.

Meriden Branch

January 17: Coal Conservation, L. P. Breckenridge.

February 14: Illustrated lecture on Fire Protection in Manufacturing Plants, Charles E. Rigby. Abstract published in THE JOURNAL, October 1918.

April 19: F. C. Bolton gave a description and demonstration of the Browning machine rifle.

May 17: Election of officers for the ensuing year, followed by paper on The Need of Systematic Training and Instruction of Workmen in the Factories, R. W. Millard.

New Haven Branch

April 16: Paper on Internal-Combustion Engines, George A. Orrok.

May 10: Election of officers for ensuing year. L. P. Breckenridge reported on the plan of the Fuel Administration to inspect all power plants of the country; informal paper on the Development of the Repeating Rifle, Edwin Pugsley.

DETROIT

January 25: Joint meeting with Detroit Engineering Society. Three-part paper presented on Complete Description and Test of a Modern Lake Steamer: Part I, Description of the Hull, H. W. Millner; Part II, Description of the Machinery, Geo. B. Turnbull; and Part III, Tests, A. G. Mattison.

May 3: Annual Meeting held jointly with the Detroit Engineering Society. Election of officers, followed by a paper on Some Factors in Fuel Economy in Boiler Plants, Robert H. Kuss. Abstract published in this volume of TRANSACTIONS and in THE JOURNAL, October 1918.

ERIE

May 3: Election of officers for ensuing year, followed by paper on The Conservation of Material, James Burke.

INDIANAPOLIS

January 25: Joint all-day meeting with the Indiana Engineering Society and American Institute of Electrical Engineers' Section. Morning Session: Concrete Roads vs. Other Types of Construction, W. E. Graves; Discussion on Roads and Recent Development in Brick Paving, E. B. Smith; Indiana Market Highways in War Time, W. S. Moore; History of an Old Bridge, J. S. Spiker; Water-Bound Gravel Roads, Karl L. Hanson; motion pictures showing construction of buildings and roads at the cantonment at Camp Dodge, Ia., presented by D. C. Franks. Afternoon Session: Recent Development in Signaling at the Front, Colonel Slaughter; Financial Problems of the Utility in War Times, J. F. Gilchrist; illustrated lecture on Concrete Ships and Barges, J. E. Freeman; Vocational and Industrial Education, A. S. Hurrell. Evening Session: Address on The Engineer and the State Council of Defense, Will H. Hays; illustrated lecture on The King of the Rail, W. S. Culver.

May 10: Election of officers. Secretary Calvin W. Rice gave an address on the Relation of the National Society to the Section, the relation of the engineer to the war, and ways in which he could assist the National Fuel Administrator and his city or community. The subject of Heat Losses in Uncovered Steam Pipes was also discussed.

LOS ANGELES

February 7: Illustrated lecture: The Practical Side of Portland Cement Manufacture, L. D. Gilbert.

MILWAUKEE

January 16: Illustrated lecture on Electric Locomotives on the C. M. and St. P. Railway, Walter Alexander.

February 13: Illustrated addresses on Cold Accumulators and Their Application to the Refrigerating Industry, E. S. H. Baars; and on the Refrigerating Equipments at the United States Army Cantonments, Alex H. Luedicke and Fred Goes.

March 13: Under auspices of American Institute of Electrical Engineers' Section, Cyril M. Jansky delivered a lecture on Science in War.

April 10: Under auspices of the American Society of Refrigerating Engineers, an illustrated address was delivered by Charles L. Fortier on Automatic Control Apparatus for Temperature Control in General, and also as applied to the refrigerating industry.

May 8: Lecture: The White Coals of Wisconsin, N. J. Whelan and V. S. Hillyer.

June 12: Illustrated lecture on Products of Electric Furnaces and the Cost of Their Production, H. M. St. John.

NEW ORLEANS

January 12: Participation in a smoker held in connection with annual meeting of the Louisiana Engineering Society.

February 11: Participation in meeting of Louisiana Engineering Society. Paper on Some Notes on Wireless Telegraphy, P. E. Lehde.

March 11: Lecture: The New Orleans Industrial Canal, A. M. Lockett.

May 13: Joint meeting with Louisiana Engineering Society. Address on Britain and the War the Last Twelve Months, Hon. T. F. Carlisle, British Consul. Secretary Calvin W. Rice delivered an address on the War Activities of the A.S.M.E. and the Need of Coöperation Among Engineering Societies. Followed by election of officers.

June 10: Paper: The Present Situation as Relating to the Introduction and Use of Natural Gas in New Orleans, Howard Egleston.

NEW YORK

January 8: Paper: Manufacturing in Relation to Banking, Research and Management, Walter Rautenstrauch. Abstract published in THE JOURNAL, June, 1918.

February 21: Subject: How Non-Essential Work Might be Turned Toward Winning the War. Speakers: Secretary Calvin W. Rice, Frederick W. Keough, William Hamlin Childs, Sterling H. Bunnell, Horace B. Cheney, President Charles T. Main, J. H. Haas, Erik Oberg, C. R. McMillen, Frank Mossberg, P. W. Henry and D. D. Jackson. Detailed report published in THE JOURNAL, April 1918.

March 19: Subject: Terminal Facilities; discussed by A. B. Pough, B. F. Cresson, Jr., W. J. Barney, George H. Pride, Ira Place and Charles Whiting Baker.

April 9: Joint meeting with the metropolitan Student Branches under auspices of the Student Branches. Brief addresses on war, educational and engineering topics by Messrs. M. H. Avram, Fred. R. Low, George A. Orrok, Prof. C. P. Bliss, Charles Whiting Baker, Ira N. Hollis, Lieut. B. F. Hart and G. Douglas Wardrop.

May 21: Subject: Labor Turnover; discussed by L. D. Burlingame, John Calder, Captain Boyd Fisher, Dudley R. Kennedy, H. E. Miles, J. J. Pearson, H. F. J. Porter, Orrin W. Sanderson. Published in THE JOURNAL, September 1918.

ONTARIO

January 29: Address on The Influence of Munition Manufacture and Other War Work on Machine-Shop Practice, F. B. Ward.

March 25: Joint meeting of technical organizations. Address by Col. David Carnegie on Need of Training the Directors and Distributors of Production. W. E. Segsworth explained the gigantic work undertaken in connection with the Invalided Soldiers' Commission.

April 18: Heat Treatment of Low-Carbon Steels, W. M. Wilkie. Published in MECHANICAL ENGINEERING, March 1919.

May 27: Secretary Calvin W. Rice gave an address on the Activities of the Society; J. H. Billings delivered a paper on the Strength of Cast Iron in Bending as Affected by Variations in Cross-Section. Officers elected for ensuing year.

PHILADELPHIA

January 22: Illustrated lecture on the War on Land and Sea, William L. Cathcart.

February 26: The Income Tax — An Engineer's Analysis, Carl G. Barth. Abstract published in THE JOURNAL, October 1918.

March 27: Joint meeting with Engineers' Club of Philadelphia. Paper on Recent Developments in Methods of Measurement, Dr. S. W. Stratton.

April 23: Dinner meeting with addresses by D. Robert Yarnall, W. S. Catell, President Charles T. Main, Past-President James Hartness, C. C. Thomas, S. M. Vauclain and W. C. L. Eglin.

May 28: Manufacture of Ordnance Forgings, George Satterthwaite.

PROVIDENCE

January 2: Illustrated lecture: The Causes of Rot in Timber, Frederick J. Hoxie.

January 15: Paper on The Development of the Submarine, illustrated by slides, by Albert Cook Church.

February 20: Illustrated lecture: Water-Power Development in New England, Henry I. Harriman.

March 4: Smoker and general meeting. Gov. R. Livingston Beekman gave an account of his experiences at the battlefront.

March 22: Lecture on War in the Air, G. Douglas Wardrop; short address on Methods of Coöperation in Meeting Present Emergencies, Secretary Calvin W. Rice.

April 9: Paper on Bronze and Its Uses, W. A. Kennedy.

April 30: Joint meeting with Rhode Island Section of the American Chemical Society. Illustrated lecture on The Manufacture of Military Primers, Lieut.-Col. Allerton S. Cushman, Ord. Dept., U.S.N.A.

ST. LOUIS

January 16: Joint meeting with Associated Engineering Societies of St. Louis. Paper on The Recovery of Gasoline from Casing-Head and Natural Gas, Paul Diserens. Abstract published in this volume of TRANSACTIONS and in THE JOURNAL, October 1918.

February 6: Lecture: The Manufacture and Use of Ammunition as Adapted to Present-Day Warfare, C. B. Lord.

March 29: Lecture: Economic Reconstruction After the War, Dr. Isaac Lippincott.

SAN FRANCISCO

March 20: Informal dinner tendered jointly to Prof. George F. Swain by the local sections of the American Society of Civil Engineers, American Institute of Mining Engineers, American Chemical Society and Am. Soc. M. E. Speakers: P. M. Downing, on Interconnection of Power Plants; D. M. Folson, on Fuel-Oil Saving; Max Thelen, on War Activities of the Railroad Commission; and George F. Swain, on National Issues of Today.

THE SPRING MEETING

Worcester, Mass., June 4 to 7

The Spring Meeting of the Society held in Worcester, Mass., June 4 to 7, was the largest in its history, there being a registration of 472 members and 514 guests, a total of 986. The professional sessions were held partly at the Hotel Bancroft, the convention headquarters, and partly at the Worcester Polytechnic Institute.

At the opening session held at the Hotel Bancroft on Tuesday evening, there were addresses of welcome by R. Sanford Riley and Mayor Pehr G. Holmes with response by President Charles T. Main, and an address on the Growth of an Industrial City by Hon. Charles G. Washburn. This was followed by a reception at the Art Museum and a dance at the Woman's Club building adjoining.

The Committee on Meetings, L. P. Alford, Chairman, in charge of the professional program, had arranged for addresses by representatives of the United States Government on the procurement program of the Government with respect to ordnance, aircraft, ships, etc.; a topical discussion on fuel economy, under the auspices of the Fuel Conservation Committee of the Engineering Council; and a session on vocational training based on the Boston system. There were the usual technical papers on general subjects and an interesting session at the Norton Companies' plants, the latter relating to the housing of workmen and employees.

Excursions planned for the ladies on Wednesday included a visit in the morning to an interesting exhibit at the Crompton and Knowles Loom Works where fancy looms were in operation. This was followed by a motor ride around Lake Quinsigamond; a tour through the plant of the Worcester Corset Company, and a trip to the Tatnuck Country Club, where tea was served. The closing festivity was held on Thursday evening in the form of a garden party at the Worcester Country Club.

Friday was reserved for an all-day trip to the cantonment at Camp Devens. Luncheon was served at the camp, after which the trip was continued through Concord and Lexington, most of the party returning by the way of the Wayside Inn, where tea was served.

The chairmen of the local committees having the general direction of the convention were as follows: General Committee, George I. Rockwood; Reception, John W. Higgins; Women's Committee, Mrs. R. Sanford Riley; Hotel, R. C. Cleveland; Transportation, James F. Healey; Automobile, John C. Harvey; Finance, William

W. Bird; Entertainment, George N. Jeppson; Printing and Publicity, Howard W. Dunbar; Chamber of Commerce, Charles E. Hildreth. Various sub-committees and individuals comprising the membership of the above committees were directly in charge of the several events of the meeting; and in fact the whole Worcester membership and their wives and many other of the local people personally helped to make the meeting the great success that it was. Every one in attendance was enthusiastic in his praise and pronounced the gathering one long to be remembered.

PROGRAM

Tuesday Morning, June 4

Registration of members and guests at headquarters.

Tuesday Afternoon

Committee meetings.

Tuesday Evening

Informal reception and dance.

Wednesday Morning, June 5

BUSINESS MEETING

Committee reports, discussion, new business.

FIRST NEW ENGLAND DAY SESSION

THE SMALL INDUSTRY IN A DEMOCRACY, George H. Haynes.

THE TEXTILE INDUSTRY IN RELATION TO THE WAR, J. E. Rousmaniere.[1]

Wednesday Afternoon

SIMULTANEOUS PROFESSIONAL SESSIONS

SECOND NEW ENGLAND SESSION

CONVERTING A FACTORY FOR MUNITIONS MANUFACTURE, John S. Holbrook.[1]

SOME ECONOMIC ASPECTS OF FIRE-PROTECTION PROBLEMS AND HAZARDS IN WAR TIMES, J. Donald Pryor and Frank V. Sackett.

OIL FUEL IN NEW ENGLAND POWER PLANTS, Henry W. Ballou.

GENERAL SESSION

A FOUNDRY COST AND ACCOUNTING SYSTEM, William W. Bird.

THE PUBLIC INTEREST AS THE BED ROCK OF PROFESSIONAL PRACTICE, Morris L. Cooke.

MOISTURE REABSORPTION OF AIR-DRIED DOUGLAS FIR AND HARD PINE AND THE EFFECT ON THE COMPRESSIVE STRENGTHS. Irving H. Cowdrey.

A HIGH-SPEED AIR AND GAS WASHER, Lieut. John L. Alden.

INVESTIGATION OF THE USES OF STEAM IN THE CANNING FACTORY, Julian C. Smallwood.

[1] Published in THE JOURNAL, July 1918.

SESSION ON SAFETY EDUCATION IN TECHNICAL SCHOOLS AND UNIVERSITIES

THE SAFETY ENGINEER, L. A. DeBlois.[1]
NEW COURSE OF INSTRUCTION IN SAFETY WORK, Geo. N. Follows.[1]

Wednesday Evening

GENERAL WAR SESSION

REQUIREMENTS OF THE NAVY, Paymaster C. E. Parsons.[1]
EXPERIENCES IN FRANCE, Dr. Irving G. Clark.[1]

Thursday Morning, June 6

SIMULTANEOUS PROFESSIONAL SESSIONS

GENERAL SESSION

EFFICIENCY OF GEAR DRIVES, C. M. Allen and F. W. Roys.
A SELF-ADJUSTING SPRING THRUST BEARING, H. G. Reist.
AIR PROPULSION, Morgan Brooks.
THE ELASTIC INDENTATION OF STEEL BALLS UNDER PRESSURE. C. A. Briggs, W. C. Chapin, H. G. Heil.
ELECTRIC HEATING OF MOLDS, Harold E. White.
STRESSES IN MACHINES WHEN STARTING OR STOPPING, F. Hymans.

FUEL SESSION

AN INVESTIGATION OF THE FUEL PROBLEM IN THE MIDDLE WEST, A. A. Potter.
TOPICAL DISCUSSION ON FUEL ECONOMY.

VOCATIONAL TRAINING SESSION

Addresses on EMERGENCY TECHNICAL WAR TRAINING by Major James E. Cassidy, U.S. Engrs., Arthur L. Williston, Lieut. André Morize[1]; motion pictures prepared for the instruction of soldiers by the Training Committee of the General Staff, U.S.A., Major Frank B. Gilbreth.

Thursday Afternoon

PROFESSIONAL SESSION

THE WORKMAN'S HOME AND ITS INFLUENCE UPON PRODUCTION IN THE FACTORY AND LABOR TURNOVER, Leslie H. Allen.

Addresses on EMPLOYEES' RELATIONS WORK:

INDIAN HILL DEVELOPMENT OF THE NORTON COMPANIES, Clifford S. Anderson.[1]
EMPLOYMENT METHODS AS FOLLOWED BY THE NORTON COMPANIES, E. H. Fish.[1]
VESTIBULE SCHOOLS, J. C. Spence.[1]

Thursday Evening

Garden Party at Worcester Country Club.

Friday, June 7

All-day trip to Camp Devens.

[1] Published in THE JOURNAL, July 1918.

No. 1636

A HIGH-SPEED AIR AND GAS WASHER

By John L. Alden, Ludlow, Mass.
Member of the Society

Nearly all of the recent improvements in air washers have been modifications of the standard form of spray-chamber washer. The author describes a new type of washer embodying a new combination of old principles. This has resulted in a very small washer with unusually high washing efficiency. Three of these washers have been built and the paper gives a brief description of the first and smallest of these.

THIS paper describes a new type of air and gas washer which has been developed within the past eighteen months, and which offers the following advantages over the existing types:

a The washing can be continued to any desired degree of cleanliness

b The washer will handle unusually large quantities of dust or long fiber without clogging, owing to its large passages and entire absence of eliminators

c Due to the high washing efficiency, the water consumption is very low, from 1 to 2 gal. per 1000 cu. ft. of air

d The washer is extremely small and compact, and of light weight. A 10,000-cu. ft. washer is about 5 ft. long, 5 ft. in diameter, and weighs less than 400 lb.

In this paper the term "air" will be used to include any gaseous fluid or vapor for which cleaning apparatus may be suitable.

2 The writer has believed for some time that air washing and gas cleaning have been approached from the wrong angle, and that most builders of apparatus for this purpose have not taken advantage of all of the natural laws governing the depositing of air- or gas-borne particles. The result has been the general adoption of crude and unmechanical designs, and has made necessary the use of low velocities of gas through the machine. Gas scrubbers normally operate at a velocity of about 90 ft. per min. and air washers at from

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

400 to 500 ft. per min., while with these devices the lin for good washing and a reasonable frictional resista 1000 ft. per min. The washer about to be described op ally at from 2000 to 5000 ft. per min. As the efficienc ing in this type increases rapidly with the velocity, the the latter is the resistance imposed.

3 Fig. 1 represents a longitudinal section of th referred to above. A helical passage is constructed zontal drum, provided at one end with a tangential dirty air and at the opposite end with an outlet for th

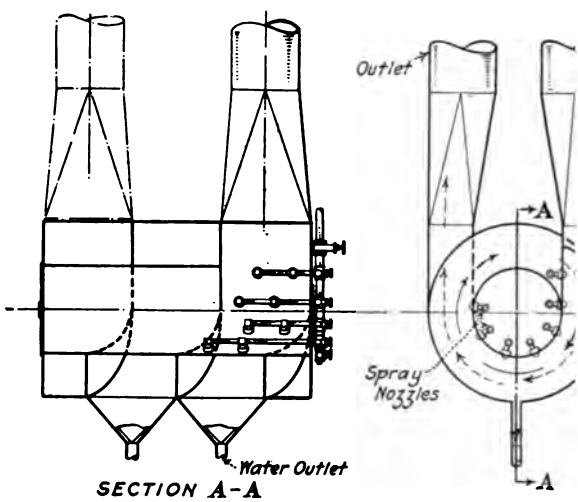

FIG. 1 LONGITUDINAL SECTION OF AIR WASHER

That portion of the helical passage nearest the inlet c washing chamber, while the remainder comprises th element. On the inner wall of the helical duct are nozzles which spray across the column of air. Depen amount of dust to be removed and the completene desired, the air makes from 1½ to 5 screwlike revoluti through the helix from inlet to outlet. For fairly du the ordinary dust-collecting system, two turns are su whole or a portion of the first turn is used for wash last turn is used for the elimination of free moisture.

4 The common commercial air washer with wh familiar depends upon its spray nozzles to throw c

sizes as small as 100 cu. ft. per min., but both the upper and lower limits of size may be extended to meet unusual requirements. Table 1 gives the approximate dimensions of centrifugal air washers to be used for ordinary ventilating purposes. For other and special cases the dimensions will, of course, be different. It will be seen that in every case the washers are very small for the capacity; those already built and installed have been so small and light that they have been hung from the ceiling with band-iron straps, leaving ample headroom beneath.

10 The new washer described in this paper will supply a field hitherto untouched by the standard air washer. The latter is utterly unsuited to the handling of large quantities of fibrous materials, cotton, jute, hemp, wool, and miscellaneous waste. Large amounts of fine dust, shavings or any other materials ordinarily

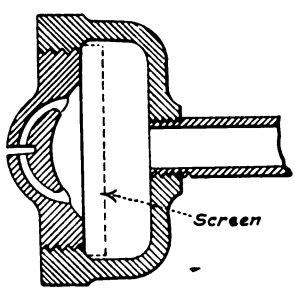

FIG. 3 FLAT-SPRAY NOZZLE USED IN AIR WASHER

handled by exhaust systems are beyond the capability of the common air washer. These substances will either clog the eliminators or will pass completely through the ordinary commercial machine. On the other hand, it is extremely difficult to clog the centrifugal air washer with dirt and refuse, owing to the large passages and to the entire absence of eliminator plates or other obstructions. It is unnecessary to interpose between the washer and the source of dust any form of dust collector or rough washer. Since the dirt and water are removed at each convolution of the helix, there is no accumulation of water and material to be reëntrained by the air current. This is an essential feature where the centrifugal removal of free moisture from a high-velocity current is attempted.

11 With the air flowing through a rectangular passage, it is desirable to throw a flat spray of water across the channel. After considerable experiment with a variety of forms, the nozzle shown

in Fig. 3 was designed to fulfill these requirements. The spraying tip is part of a removable plug containing two holes designed to throw opposing streams. The impact of the jets forms a flat sheet of spray at right angles to the plane of the holes. Although this spray is quite fine, much of it is further broken into mist upon striking upon the opposite wall of the washer. Locating the spray nozzles upon the inner wall of the chamber makes it necessary for all of the dirty air to pass through this fog-filled passage. This arrangement is much superior to that whereby water is allowed to flow from perforated pipes or nozzles over the outer cylinder alone, as it insures a thorough wetting of the dust.

12 The pressure loss through the washer is from $\frac{1}{8}$ in. to 1 in. of water, depending upon the conditions governing the design. The variables to be considered are the diameter, the cross-sectional area and proportions of the washing space, the velocity, the number of turns of the helix, and the volume of water per square inch of the sectional area of the washing chamber. Ordinarily this washer can be designed for ventilating work with a resistance of about $\frac{1}{4}$ in. of water. Where the dust requirements are more severe, demanding higher velocities, more wash water and a greater number of convolutions of the helix, the loss will be somewhat greater.

13 Unfortunately the writer is unable to give additional details of the performance of this washer, as his investigation of the first commercial installation was interrupted in May 1917 by the war. However, it may be said that two others were built from his design, and although he has not seen these either during construction or operation, they are reported by the owner to be in successful operation. Each of the later washers has a capacity of 15,000 cu. ft. per min., and was designed to hang from the ceiling with 7 ft. of headroom beneath. This type of washer was designed and developed for a specific job — that of washing the clouds of dust from the fan blast of dust-collecting system, leaving the air fit for breathing. The first experimental installation and the subsequent machines showed that for this purpose the washer was eminently satisfactory. The severe test of dust-collecting work, removing great quantities of dust from the air and returning the purified air to the room, justifies the belief that the centrifugal washer will easily satisfy ventilating requirements. Owing to the similarity of refined dust washing and blast-furnace-gas scrubbing, an investigation of the adaptability of this washer to gas cleaning would seem well worth while.

DISCUSSION

F. R. STILL (written). The American Blower Company long ago decided that for the removal of dust from air in industrial institutions a much different type of air-cleaning device is necessary than is required in ventilation plants for public buildings. It was also discovered that devices designed along such lines as are covered by the paper cannot be used in public buildings, because of the noise they make. Air must be moved at low velocities to obviate noise in public buildings.

Furthermore, smaller quantities of water are generally used and the spray must be produced more in a mist form for the purpose of regulating the humidity. Nearly all the air-cleansing devices put into public buildings are for the purpose of "conditioning" the air, which in its final analysis means removing the dirt and bacteria and producing the right humidity for healthful conditions.

In industrial institutions noise is not a prime factor; furthermore, it is seldom that air conditioning is a feature of first importance. In some institutions it is necessary to be able to return the air back into the building after cleansing, because of the size of the exhaust fans, which in such cases will remove so much air from a department that it becomes too expensive, if not impossible, to heat the department.

In some installations we have successfully used the standard type of cyclone separator, making slight interior modifications such as putting a standpipe up through the middle with a rose spray of ample capacity to keep all the interior surfaces thoroughly wet. Through centrifugal action the dust as it enters the cyclone strikes the surfaces wet by the spray, and as it keeps rapidly whirling, the moisture absorbed adding to the specific density of the dust, the cleansing effect is very thorough. We have applied this apparatus to a number of chemical plants and also to some shoemaking machinery plants with success. Wherever we have so applied it, we have simply selected a separator of the same proportions we would have selected to use for a similar capacity for dry cleaning. Provision must necessarily be made against freezing in very cold weather whenever water is used.

W. H. CARRIER (written). This paper presents a mechanical modification of one of the oldest types of washing devices that has been used. It varies little in principle from the cyclone type of dust

separator, provided with spray nozzles, which has long been used in dust collectors.

The same principle is also employed in the well-known Theisen type of scrubber, extensively used in this country and abroad for washing the gases from blast furnaces and from gas producers. In this type the air is rotated mechanically by means of paddle wheels, and while the air follows the same spiral course, the spirals are not mechanically separated by radial partitions or spiral diaphragms as in the case of the washer that the author describes. The speed of rotation of the gas or air, however, is much greater in this type of scrubber, varying from 7000 to 15,000 ft. per min., depending upon the degree of washing desired and the nature of the material to be be extracted. At the higher velocities this will remove even the finest particles of soot and smoke, which will not be accomplished at the lower velocities suggested by the author.

There are numerous installations of the centrifugal-separator type, provided with a spray and operating on the same principle, in use in munition factories for the separation of gunpowder dust from the air before going to the general exhaust system. These are operated on the suction side of the fan instead of on the discharge side, which of course is necessitated by the fact that it is not permissible to draw this dust through long ducts or through fans before separation.

Where only a few turns or spirals are used in the separation, as suggested in the paper, I am doubtful that the radial partitions or diaphragms separating the rotating streams of air are essential from the standpoint of effectiveness, and possibly they are objectionable from a mechanical and operating standpoint. In a spiral of a larger number of turns, however, this construction would be of advantage, as the same velocity of rotation would be maintained through the entire length of the spiral travel of the air

The type of washer described by the author is especially adapted for relatively small air quantities handled at high fan pressures and where the air contains a great deal of coarse foreign material. Its efficiency, however, for a given proportional design is limited by the size of the washer, as was pointed out by the author. The centrifugal force at a given velocity will vary inversely as the radius, and therefore inversely as the square of the capacity of the unit. Furthermore, the effectiveness in dust separation of a given centrifugal force in an air stream varies directly as the radial dimensions or width of the rotating air stream, i.e., the average distance

through which the particle of dust is to travel before it reaches the peripheral surface where it is eliminated. Therefore the author's conclusion that the effectiveness of washing varies directly as the centrifugal force, may not be completely correct. The effectiveness of the washing for a given proportion will vary inversely as the product of the width of the spiral stream times the mean spiral radius, divided by the square of the mean velocity of flow.

Mr. Alden has failed to present definite data regarding pressure losses in this type of washer at different velocities and I am certain that he is in error regarding the loss occurring where it is necessary to increase the velocity to obtain the required cleaning effect. The loss in static pressure at maintained velocities is not the primary thing to be considered, but the loss required to give the air the necessary high velocity to secure the separation must be considered as well. In this type of separation it is probable that a velocity from 3000 to 5000 ft. per min. is necessary for efficient results, depending upon the capacity and the number of spirals. To create a velocity of 4000 ft. per min. will in itself require a pressure of 1 in. of water. In addition to this, there is a frictional loss proportional to the square of the velocity through the air passages. This loss will be in the neighborhood of 0.4 in. for each complete spiral revolution where the velocity is 4000 ft. per min. With two spirals this would be about 0.8 in., or a total pressure of 1.8 in. would be required. Some of the energy in velocity may be recovered by conversion to pressure by the use of a diverging nozzle at the discharge. The efficiency of this conversion will depend in a large measure on the proportioning and shape of the discharge nozzle. From the fact that relatively high velocities are required for effective results with larger capacities, it is evident that this type of washer is particularly adaptable to small capacities where high velocities and pressures are the rule, as, for example, in dust-collecting systems.

For commercial application in ventilating systems, I disagree with the author completely as to its applicability and desirability. Ventilating requirements are usually for larger quantities of air and do not permit of excessive losses or of high velocities such as required for handling large quantities of air with sufficient cleaning results. This has been the reason that this type of washer has not been developed, as certainly it was well understood by all designers of air-washing systems and was rejected on the foregoing grounds. If it were attempted to use this system in ventilating work, the velocities to obtain any degree of efficiency would be so high that the

pressure losses would be prohibitive from a standpoint of power required. The object of the present commercial air-washing devices is to overcome this difficulty by splitting up the air into a large number of parallel layers, each subjected to a centrifugal action, which will be efficient in removing the dust. As pointed out previously, the narrower the air passage, the more efficient is the removal and the greater the centrifugal force. For this reason air washers have come to be designed with a relatively narrow air passage in the eliminator or washing plates, some washers using less than 1 in. of free space between the plates. It is necessary that the velocities be kept down to a point where the losses are commercially practicable. This is between ¼ in. and ½ in. The same result can be secured by the author's method by using a number of small individual spiral separators, but such construction would not only be far more expensive, but would be so bulky as to be prohibitive in most installations.

In conclusion, I might mention another form of centrifugal washer which has long been in use in gas plants and which embodies the same centrifugal principle, although in a much more efficient manner and a more practicable construction for large quantities. In this type the air passes through very narrow spiral involute passageways, from the outside to the center of a vertical cylinder or tower. Hence it passes in a reverse direction outwardly through a parallel path to the periphery of the cylinder or tower. The velocity through these passageways is maintained at about 4000 ft. per min. by varying the height of the passageways by means of a water column or level, the height of which is varied according to the capacity requirements. The water spray is introduced from the top of the tower. This type of tower produces effective cleaning of the gas. The pressure loss through the tower, however, is considerable, but it is always necessary to bear in mind in discussing the methods of air purification that the degree of purification is inseparable from two factors: One is the amount of surface over which the air must pass, and the other is the pressure loss sustained by the air in passing over this surface. One type of washer will do practically as well as another, providing the product of pressure loss and surface is the same in both and sufficient water is supplied to maintain the surfaces in wet condition. If efficiency of washing is based upon the ratio of cleaning effect to the power required, then the efficiency of the given air-washing device will vary directly as the mean of washing surface used, assuming that the surface is everywhere utilized in producing centrifugal action or impact upon the stream of air.

HENRY P. GALE (written). The nozzle described in the paper was developed in the laboratory of the Oneida Steel Pulley Company's fan department in the spring of 1915. It was used on a job handling 20,000 cu. ft. of air per min. They removed each 10 hr. an average of from 1½ to 2 iron wheelbarrow loads of mud and lint. At first the water was recirculated. After some months the warm water from the condenser was used. This warm water held the humidity to the point required for their work. I have never used a screen in the nozzles, but since Mr. Alden left our employ we have added very much to the value of the nozzle shown in Fig. 3 by making the outlet V-shaped instead of straight. By changing the width of the V, any size of drop to a mist can be secured. One nozzle at 50 ft. head will fill with mist a room 15 × 15 × 10 ft.

If the work to be done does not call for the air to be delivered in any particular direction, I should prefer the open centrifugal machine, for by using a helix body the shortening of the radius at the last part of the body aids materially in pinching out the mud and water, leaving the air dry. As the centrifugal force varies inversely as the square of the radius, the change in the radii of a properly proportioned helix for the body aids in several ways. As the dust content has been large in all of the work that we have undertaken, we have been obliged to maintain a high velocity and short radius to the chambers. In handling over 10,000 cu. ft. of air per min. from one fan it has been good practice to build the washers in small units placed either tandem or in series. The time necessary to wet the dust content is best secured by increasing the length of the washing chamber if the quantity will not allow of the use of a short radius. This length has never been made less than one-third nor over two-thirds of the circle. The amount of the dust content determines the length of the washing chamber.

THE AUTHOR. The conclusions drawn by Mr. Still and Mr. Carrier are, in the main, correct, in so far as they relate to the use of this washer in ventilating work. Except for certain special cases in this field, the writer's plans for the commercial development of this washer have followed the lines of dust-collecting, gas-scrubbing and chemical processes where the intimate contact of a gas and a liquid is desired. The pressure necessary to produce the high velocities mentioned in the paper is not a loss which can be charged against the washer, since velocities of the same order of magnitude are already present in practically all dust-collecting systems.

No. 1637

INVESTIGATION OF THE USES OF STEAM IN THE CANNING FACTORY

By Julian C. Smallwood, Baltimore, Md.
Member of the Society

The increased demand for American food products coming coincidently with a scarcity of fuel has created a condition in packing houses calling for a more exact knowledge of steam distribution and consumption than the packer has hitherto deemed necessary. Although very little is known about either the actual or necessary steam consumed in the various units of the canning factory, it is certain that large wastes are prevalent. Furthermore, the subject is timely, not only because of the necessity for economizing fuel, but because of the shortage of all classes of equipment. Many packers are called upon to increase their output by 50 to 100 per cent. This means, besides the extra special apparatus required, more boilers and power-plant units; and the question then arises how much steam is definitely needed for a given output.

This paper analyzes the different heat processes in the canning of food and points out actual and ideal steam consumptions and methods of minimizing wastes.

It is not the writer's purpose to deal in this paper with the economies possible in the generation of steam in the canning factory. Although it would well repay the packer to inform himself on this subject, since in the boiler room any amount up to 50 per cent of his coal may be wasted, the principles of economical boiler-room operation are well understood by mechanical engineers and are no different in the canning factory from any other. The principles and the best practice in the use of steam, on the other hand, are not common knowledge, and will therefore engage the writer's attention.

USES OF STEAM IN CANNING FACTORIES

2 First in an enumeration of the various packing-house units requiring steam are engines to turn the lineshaft and operate cranes and conveyors, and, possibly, pumps for supplying water. Next in order is the apparatus to give the raw material a preliminary heat treatment. In the case of tomatoes, this is a scalder which loosens the skins; in the case of peas, beans, spinach, etc., it is a bleacher which

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fixes the color of the product and washes away impurities and partial decay. At this stage some goods are placed in the cans, but for others heat must first be applied in bulk in order to evaporate water and concentrate the product. For example, tomato pulp or paste must first be boiled down, as must also fruit juices in the manufacture of jellies and preserves. If the material requires such reduction, it is next introduced into a kettle supplied with a steam jacket for evaporation, or a tank supplied with steam coils, or into some form of evaporator using steam as a source of heat for evaporation. If the material does not require such reduction, it must next be sent through an exhaust box the chief function of which is to produce a partial vacuum in the capped can by expanding its contents previous to capping. The expansion is accomplished by heating the cans by direct contact with steam in the exhaust box. After the cans are capped they are packed in metal cages and placed in a "process kettle" or retort, where they again are subjected to steam heat for the purpose of sterilizing and cooking. Finally, upon removal from the process kettles, the packed cans must have their heat removed, which is usually effected by a water bath and which completes the heat processes of production.

ANALYSIS OF THE HEAT DISTRIBUTION

3 An analysis of the heat distribution leads to the following conclusions: First, as a rule, the mechanical power required is comparatively small, and this limits the possibilities of exhaust steam. Second, except for products that must be reduced by evaporation, the directly useful heat functions simply by elevating the temperature of the raw material from that of the room up to whatever temperature is carried in the process kettle. Assuming, for example, that the temperature of the raw material is 80 deg. fahr. and the temperature of the process kettle is 212 deg., the difference is 132 deg., and the useful heat in the whole process of canning is numerically equal to the total weight of the can contents multiplied by 132 deg. multiplied by the specific heat. To this, of course, must be added the heat of vaporization when the product is reduced, which, however, is only the case for certain products.

4 This may seem a startlingly simple conclusion to be formed from a complex problem, and yet, truly, there is no other one. Cooking and sterilizing are merely a matter of elevating a temperature and maintaining it. Once the temperature is attained it can be held, under ideal conditions, without further consumption of heat

Heat consumed for any other purpose is either for an auxiliary process or is a total loss through inefficiency of the main process. This principle finds an application in a small way, in domestic kitchens, in the fireless cooker. The old-fashioned coal stove and the more recent gas range both waste enormous amounts of heat, because after the temperature of the cooking material has been raised, heat continues to be consumed, and is wasted by radiation from the containing vessel and by convection currents.

5 Similarly in the canning factory, from the time the raw material enters the exhaust box up to the time it leaves the process kettle, the one desirable effect is the elevation of temperature. In the exhaust box this is partially accomplished, possibly with the expenditure of a disproportionate amount of steam. Between this stage and the process kettle the can is being capped and packed in the crates, during which handling it may radiate some heat which will have to be restored. Finally the sealed cans are placed in the process kettle. Heat is transferred to them and, incidentally, radiated from the surface of the kettle, blown right through the kettle (especially if an open water bath is used), and wasted through an overflow of hot water.

6 For the purpose of obtaining an idea of the quantitative values of these heat transfers, Fig. 1 has been prepared showing the distribution of heat in a packing house putting up tomatoes. An arrangement using steam inefficiently has been purposely shown in order to indicate the possibilities. It is assumed that this plant is equipped to handle 10,000 baskets per day of 12 hours, that the tomatoes are canned whole, and that skin-and-core pulp is put up as a by-product. A fair value for the yield is seven No. 3 cans of whole tomatoes per basket, and one No. 3 of pulp. This will make a total of 70,000 cans of the former and 10,000 cans of the latter per day of 12 hours.

7 Taking as the heat unit the boiler horsepower, which is equivalent to about 30 lb. of high-pressure steam per hour, or, more exactly, 33,479 B.t.u. per hr., and assuming the temperature elevation to be 132 deg., the useful heat added to the whole tomatoes amounts to 57.5 boiler hp. The pulp must not only be elevated in temperature but thickened by evaporation of some of its water. Assuming a reduction of 5:4, the boiler hp. necessary is 18.5, making a total of 76.

8 Of the useful heat to the whole tomatoes only 9 boiler hp. is added in the exhaust box, the remainder being added in the process

kettle. The figures in Fig. 1 enclosed in circles represent the waste heat either through exhaust steam, or hot water from drains, or radiation.

9 These heat quantities may seem excessive, but it should be remembered that they vary in each of the particulars very considerably in different plants. The distribution shown may be considered on the whole not unrepresentative.

10 A study of this example shows that there are two general methods of obtaining heat efficiency in the use of steam. First, by improvements in the construction and operation of heat-transfer

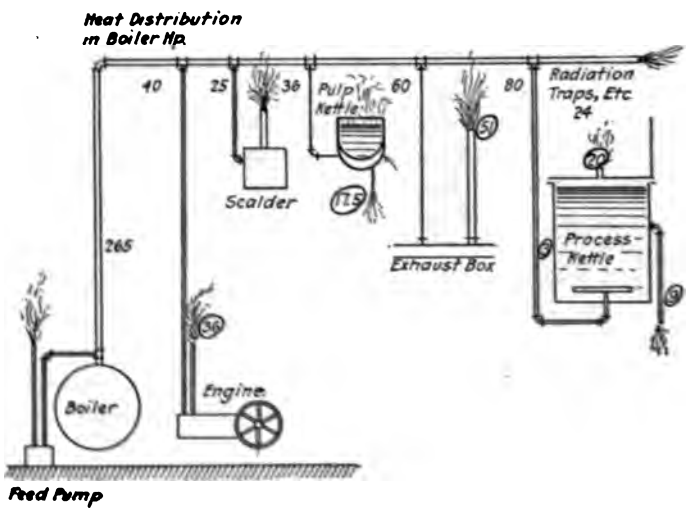


FIG. 1 TYPICAL STEAM DISTRIBUTION

apparatus, and second, by establishing a coördination of units so that what has ordinarily been considered as waste and irrevocable heat may be recovered to the fullest extent possible. These requirements do not exist independently. Let us then consider first the efficiency, or lack of efficiency, of the various steam-using units familiar to the canning factory, having special regard to the possibilities of eliminating steam wastes, and with all due respect to the paramount necessity of capacity.

BLANCHERS AND SCALDERS

11 Blanchers and scalders both make heavy drains on the steam pressure, but they are not of such general interest as the other items listed, and may be discussed briefly. In their operation, water and

steam are led to a single chamber, circular or rectangular in cross-section, through which also the vegetables or fruit are fed. In blanchers the steam heats the water which is constantly overflowing, and excess steam is carried through a vent flue to the roof. Upon meeting the hot water, the raw material is washed free of its gummy coating, etc., which gradually contaminates the water and necessitates a continuous supply. The incoming fresh water requires more steam to maintain the temperature. Furthermore, steam must be added in sufficient amount to counteract the cooling effect of the entering food. From these considerations it becomes apparent that an exercise of judgment is required to regulate the water and steam supply to the rate of the food material to secure the best economy with steam. The water should be fed in just fast enough to maintain the minimum degree of purity consistent with the requirements. Any greater amount of water necessitates more steam, the heat of which is wasted through the overflow. Any greater amount of steam than is necessary to maintain the temperature merely blows through the vent flue. Obviously, two or three times as much steam as is necessary may be consumed if regulation is neglected.

12 In the operation of tomato scalders a similar conclusion may be drawn. Here the steam and water do not mix, that is, intentionally, it being the purpose to have first the steam and then the cold water strike the raw material. Steam at 80 to 100 lb. pressure is supplied through a 2-in. pipe and passes through a series of perforated holes in pipes placed above and below a conveyor chain carrying the tomatoes. The bed of fruit is something like four to six inches thick, and it is expected that these steam jets will penetrate the mass and heat their outer skins in about ten seconds. Now in the same chamber in which the steam is working, and just beyond the steam jets, are jets of cold water. There is no dividing partition, and the result is a splendid condenser effect. As the water must be kept cold, more of it than otherwise necessary is turned on to counteract this effect, thereby enhancing it. Provision is made through a vent flue so that if any steam escapes both water and tomatoes it can go out through the roof.

13 Obviously, with the application of ingenuity and experiment the steam consumption of these machines might be materially lessened through radical structural changes without impairing effectiveness or capacity. On the other hand, and opposite to the case of bleachers, it is difficult to secure steam economy by nice regulation alone — for one reason because of the prejudice of operators. The

writer himself has, during operation, cut down the steam valves on scalders from full opening to one-half turn, and the girls peeling the tomatoes never knew the difference. But once let them *know* that the steam is reduced, and they will insist that the tomatoes are not scalded enough!

14 Another instance of the effectiveness of supervision: Tomatoes are dumped from baskets on to the conveyor leading to the scalder by two untutored negroes. Due to the lapses between

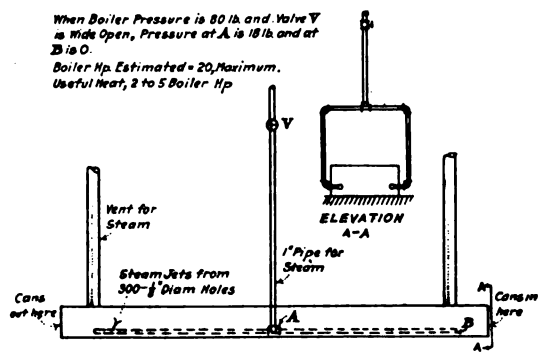


FIG. 2 EXHAUST BOX

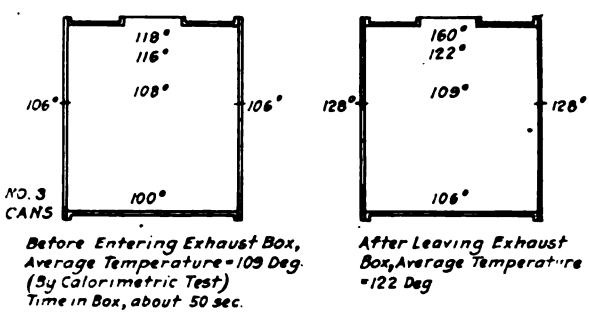


FIG. 3 TEMPERATURES ATTAINED IN EXHAUST BOX

baskets, the conveyor chain travels 5 ft., then receives a charge, then another idle 5 ft., and so on. Each basketful forms a small pyramid, 8 to 10 in. deep at the apex. The tomatoes on the outside are scalded sufficiently, but those at the thick part of the mass hardly at all, whereupon the girls handling the latter demand more steam. By the simple expedient of having the tomatoes distributed on the conveyor chain in an approximately uniformly thick bed, about 50 per cent of steam is saved.

EXHAUST BOXES

15 Exhaust boxes are now to be considered. In the home-made form (see Fig. 2) these are long rectangular boxes made of four planks, open at the ends, and through which a conveyor chain passes bearing the filled but uncovered cans. Drilled pipes within the box are used as steam jets playing on the cans. At the ends of the box are flues, so that when the steam is fully turned on it will not pass into the packing room but out through the roof.

16 It is at once apparent that it is out of the question to obtain anything like a uniform temperature of the can contents in the small space of time that they are subjected to the steam, particularly if

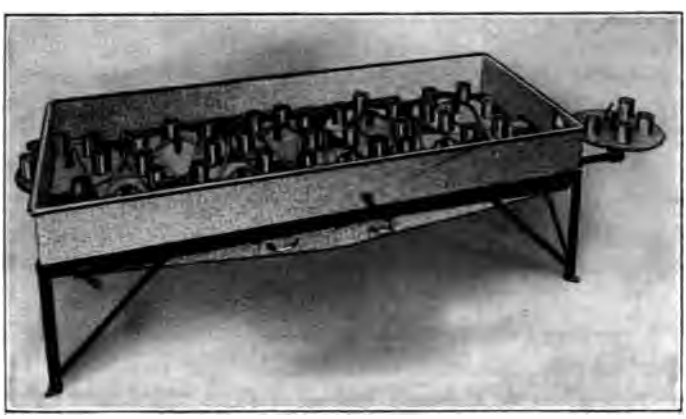


FIG. 4 IMPROVED FORM OF EXHAUST BOX

they are packed closely and contain little liquid. Fig. 3 shows the results of some temperature measurements made by inserting a thermometer at different points. The average temperatures were obtained by calorimetric determination. It is thus seen that although it is the intention to elevate the temperature of the cans to about 160 deg., nothing like this is accomplished. If it were, the original temperature being about 100 deg., the useful heat (that is, heat actually transferred to the cans) would be 16 boiler hp. for the conditions shown in Fig. 1. Actually, the useful heat is only 2 to 5 boiler hp. (corresponding to temperature ranges of from 5 to 20 deg.). In Fig. 1 a temperature rise from 80 deg. to 120 deg. is assumed. The heat consumed in the form of steam may be as much as anything between 20 and 30 boiler hp., making for a thermal efficiency of

about 10 to 15 per cent. Where does the difference go? Through the roof.

17 The performance of the exhaust box as regards steam economy may be materially bettered by the careful regulation of the steam supply. From trials which the writer has made, involving temperature and pressure measurements, he has found that the steam can be cut down from full on to about one-half a turn of the stop valve in some cases without materially affecting the temperature elevation. That is, the heating effect is nearly as good when the steam merely trickles through as when it pours through. To gain effectiveness, the time during which each can is subjected to the steam must be lengthened, and the greater the time, the greater will be the machine's efficiency. This fact is being recognized by the manufacturers of modern forms of exhaust box, which are so shaped that the length of the path through them is greatly increased, thereby increasing the time of heating (to 5 and 15 min.). Such a box is shown in Fig. 4.

18 Much can be gained if the exhaust box is in part relieved of its effort by introducing whatever liquor goes with the solid part of the contents as hot as possible. As previously mentioned, after the solid material is placed in the can, either by machine or hand, liquor is added either in the form of brine, syrup, or fruit juice. This liquor is previously heated, but between its heating and the time of introduction into the can it often is allowed to cool, either by halts in the procedure or through radiation from pipes and containing vessels. In every case the liquor should enter the can at about 210 deg., which high temperature may so elevate the average temperature of the packed material, especially in hot weather when the initial temperature of the solid is high, as to make the additional elevation by the exhaust box trifling.

JACKETED KETTLES

19 Turning now to a consideration of the various packing-house units used for concentrating liquid foods and food juices, which units may be termed generally "evaporators," it will be noted that there are many different forms and types. Perhaps the most elementary form, and in some ways the most interesting, is the jacketed kettle (see Fig. 5). In shape this is the same sort of utensil as the old-time housewife used, but of course is larger, having a capacity of between 50 and 500 gal. It receives its heat from the steam jacket whence it gets its name. The jacket is tapped with one or

more openings to receive the steam pipes and another opening for the drain pipe to carry off the condensed steam.

20 The performance of these kettles is very interesting in many ways. In the first place, it may be observed that under approximately ideal conditions their thermal efficiency may be nearly 100 per cent, the only loss being from radiation of heat from the outside of the jacket. This assumes that the condensate from the jacket is returned to the boiler through a return trap, which, however, is not always — or even often — used. Steam at 100 lb. gage pressure has a temperature of 338 deg., so if steam of this pressure is used in the jacket of a kettle, it will, after condensing in the jacket, emerge from the drain pipe as water at 338 deg. If this hot water is returned

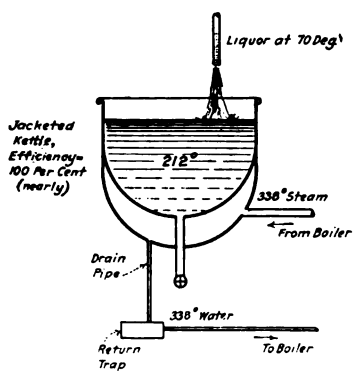


FIG. 5 HEAT TRANSFER IN JACKET KETTLE

to the boiler by a return trap none of its heat is lost (except that small amount due to radiation), and practically all of the heat given up by the steam goes to the useful purpose of evaporating water from food material.

21 There are, however, three other ways in which steam may be handled (see Fig. 6). First, the drain may be passed through an atmospheric trap, which necessitates that the water be reduced to below 212 deg. before it can be returned to the boiler. In this case the efficiency of the system is 87 per cent, and 13 per cent of the heat consumed is wasted. Practically the same thing may be accomplished if the drain pipe is without a trap, but is supplied with a stop valve so regulated that only water will be discharged. Second, the kettle may be supplied with an atmospheric trap, or a stop valve in the drain pipe as just described, the discharge from which is not returned to the boiler. In this case, if feedwater at 70 deg. is used

to make up the 212-deg. water which might have been used, the waste is 24 per cent and the efficiency only 76 per cent. Third, the kettle may be unprovided with a trap of any kind, and the valve in the drain pipe left so wide open as to let large quantities of steam escape as well as condensate. Here it is difficult to estimate the ensuing waste, but if one is to judge by the ascending clouds of steam, it must be enormous.

22 Many operators of these and other steam-using units in the canning factory labor under the delusion that a violent commotion and an ear-splitting racket are evidences of rapidity. Hence they will turn on the steam until their eyes and ears are satisfied in these

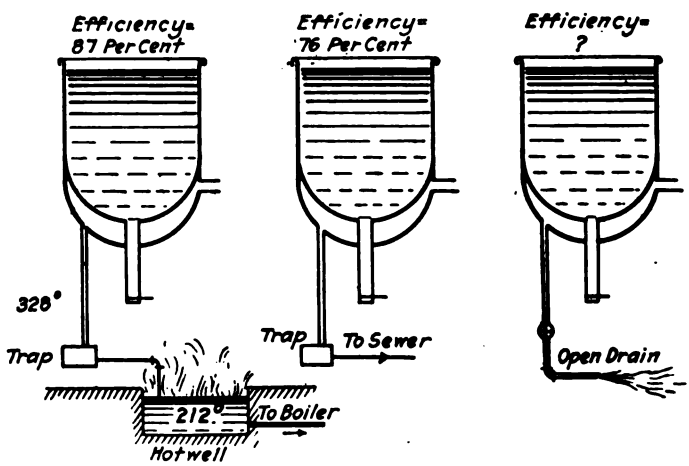


FIG. 6. DRAINAGE SYSTEMS FOR JACKETED KETTLES

respects. Unless means are taken to prevent such excesses through traps and other fool-proof devices, it is impossible to eliminate wastes.

23 Before leaving the subject of jacketed kettles, a word must be said about their performance as regards capacity. Judged as an evaporator suitable for high rates of evaporation, it would seem, offhand, that nothing could be cruder. There is absolutely no provision made for systematic circulation of the kettle contents, which matter of circulation is given most careful thought in the design of steam boilers. A jacketed kettle in full blast shows the most haphazard ebullition, and one would suppose that a much more effective rate of evaporation could be obtained if the circulation could be assisted. In spite of this, the fact is that this apparatus is a remarkably quick evaporator. Results that have come to the writ-

er's attention show, with the use of 100-lb. steam, as high as 8.5 gal. or 70 lb. of liquid evaporated per square foot per hour after the mass has come to a boil. This corresponds to about 700 B.t.u. of heat transferred per hour per square foot per degree difference of temperature, a figure comparing very favorably with the best types of feedwater heaters and condensers, which class of steam-engineering apparatus the jacketed kettle most closely resembles as regards heat transfer.

24 Jacketed kettles differently installed show very different capacities for evaporation. The question then arises, What are the factors affecting the rate of evaporation? A study of this question shows that the total amount of water a kettle can evaporate per hour may be affected chiefly by the pressure of the steam in the jacket. The rate of heat transfer is directly proportional to the difference in temperature between the boiling material (about 212 deg.) and the substance supplying the heat, that is, the steam. Now, since the temperature of steam increases with its pressure, the high-pressure steam is more effective in rapidity. But if the steam pipes are too small, or if the kettle opening for steam is not large enough, there may be a considerable drop of pressure of the steam before it reaches the jacket, and a still further drop after it gets into the jacket. In consequence, and especially if the steam is initially wet, it falls in temperature and loses some of its effectiveness. In this connection it is appropriate to remark upon the prevalent packing-house custom of economizing on pipe sizes. A kettle with a bushed steam opening cannot evaporate as fast as one with an unrestricted supply. Even under the best conditions it is a matter for speculation whether or not the steam pressure in the jacket is not materially less than that in the steam pipe because of the condenser effect of the comparatively cool liquid within the kettle. At all events, much can be done to improve capacity by using carefully calculated pipe sizes, and by *introducing the steam into the jacket through two or more openings instead of only one.* A series of experiments with the purpose of learning the pressure within a steam jacket for different systems of piping would, it is felt, disclose facts of practical value in future design.

25 The capacity of a jacketed kettle may be much reduced by the cooking material caking to its sides. To avoid this condition, kettles are frequently equipped with mechanical stirrers which continuously wipe the heating surface, thus keeping it clean. This action also imparts a velocity to the boiling liquid at the heating

surface which, presumably, affects the heat transfer, but just how much is not known. Similarly, the quantitative effect of high velocity of the steam in the jacket is unknown.

COIL EVAPORATORS

26 The final limitation to capacity has to do with the area of the heating surface. In this respect the jacketed kettle bears about the same relation to evaporators of refined design, such as vacuum pans, as the first shell boiler to present-day water-tube boilers; that is, it is deficient in heating surface. The obvious step, then, is to add heating surface in order to increase capacity, and this has been done. The additional surface takes the form of basket or ring coils, or nests of tubes, whereby the heating surface can be tremendously

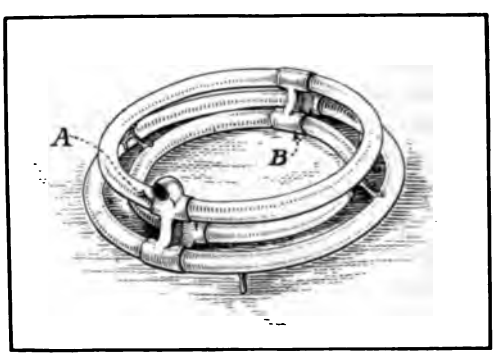


FIG. 7 STEAM COIL

increased. There is, however, an undetermined limit to the effectiveness of such additions, since they may retard the circulation of the boiling material to such an extent as to decrease instead of increase capacity.

27 Coils offer such an attractive way of forming a compact heating surface that they have come into favor in units which dispense entirely with the steam jacket. Any form of containing vessel may be used for the liquid to be concentrated, and the vessel may be made of any appropriate material. Jacketed kettles are commonly made of copper; the containing vessels for coil evaporators may be made of wood, thereby making a great saving of expense. Also, a wooden vessel with coils occupying a given floor space may contain vastly more heating surface than a jacketed kettle occupying the same floor space, and therefore have considerably

greater capacity. In such a case the coil evaporator also loses less heat by radiation from the containing shell, but otherwise the heat efficiency of the coil may be just as good or as bad as that of jacketed kettles previously cited. The effectiveness of a single square foot of heating surface of the coil is, it is believed, possibly less than that of the jacket, particularly if the coil is not carefully designed. "Effectiveness" in this connection means the number of heat units that can be transferred per hour from the steam to the liquid contents. As mentioned before, the efficiency may be nearly 100 per cent in each case. Fig. 7 shows a coil of modern design taking steam through the manifold at *A* and exhausting from drain *B*.

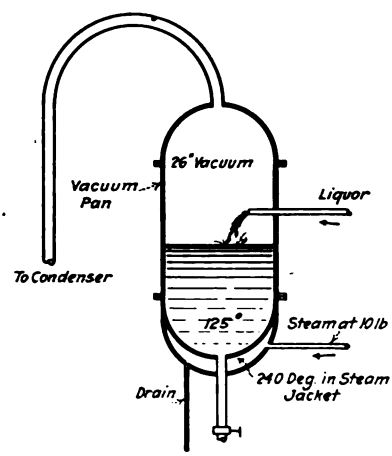


FIG. 8 VACUUM PAN

28 Evaporators depending upon coils or nests of tubes suffer two serious disadvantages: First, they are much more difficult to clean and to keep clean than are jacketed kettles. Mechanical wipers, as stirrers, are out of the question, and hand cleaning is awkward. Second, they are, with poor design, more apt to leak steam into the liquid to be evaporated than are jackets, whereby both heat and capacity are lost.

VACUUM PANS

29 In the writer's opinion a type of evaporator which will eventually enter the canning factory is the vacuum pan, Fig. 8. The advantage which it possesses is that it can use exhaust steam efficiently, and, when live steam is employed the pan may be so

designed as to take only half or less than half the steam required by apparatus which boils at atmospheric pressure.

30 The subject of vacuum pans is too large a one to enter upon here, there being many different designs and principles involved. It may be mentioned, however, that the whole subject is replete with unsolved problems which give much opportunity for successful research work.

31 All of the evaporators cited may meet a check in their capacity when certain products are handled, through the thickening

TABLE 1 PERFORMANCE OF EVAPORATORS

Type of evaporator	Evaporation, lb. per sq. ft. per hr.	B.t.u. transferred per sq. ft. per hr. per deg. fahr. difference in temperature
Jacketed kettle with 100 lb. steam pressure, by test	66.6	660
Jacketed kettle with 50 lb. steam pressure, assuming the same B.t.u. rate of transfer	45.0	.....
Jacketed kettle with 25 lb. steam pressure	29.0	.....
Shell evaporator, with paddles, 50 lb. steam pressure, by test	41.5	625
Coils, 100 lb. steam pressure, by test	60.0	628
Vacuum pan, single effect, 25 lb. steam pressure, on tomato paste; average, by test	40.0	312
Vacuum pan, maximum, 100 lb. steam pressure	105.0	660
Vacuum pan, with 10 lb. steam pressure, single effect, and 26 in. vacuum	64.5	600

TABLE 2 COMPARISON OF HEATING-SURFACE REQUIREMENTS OF KETTLES AND COILS

Capacity of kettle, gal.	100	300	500	600 (tank with coil)
Heating surface per gal. of contents, sq. ft.	0.10	0.08	0.66	0.053

and foaming of these products. To avoid boiling over, foaming necessitates a cutting down of the rate of evaporation. Similarly with thickening — the resulting increased viscosity of the mass causes a spattering dangerous to operators and wasteful of material. In such cases the initial rate of evaporation must be lessened toward the end of the process. The remedy is evaporators with high sides to prevent boiling over, and stirrers to prevent caking.

32 Another item which should be carefully calculated for individual evaporators as well as a number of them together is the drain-

age of the spaces supplying steam. It is very easily possible to flood these spaces with water, either through too small a pipe size for the drain from the jacket or coil, or by having one unit flood another, or by a badly designed unit of which coils are a conspicuous example.

COMPARATIVE PERFORMANCE OF EVAPORATORS

33 Table 1 shows the comparative performance of these various evaporators. It should be remembered upon considering the results indicated in this table that the data have been obtained for the most part under packing-house conditions and that the results should not be considered as exact, especially in view of the fact that they were obtained from only a few tests. They may, however, be considered as conservative, since other tests, the results of which have been brought to the writer's attention, show considerably higher values, particularly in the case of jacketed kettles; values so high, in fact, that he hesitates to quote them.

34 In Table 1 the first three lines show the effect of using steam of a lower pressure than 100 lb., the rate of evaporation in pounds per square foot per hour rapidly falling off with the lower-pressure steam. The low result of the shell evaporator may be explained possibly by the effect of the design, in that the heating surface was so arranged that part of it could be flooded during operation. It is seen from the table that the best results were secured with the jacketed kettle. This fact is very much influenced by the steam connections, in that if only one is used the rate of evaporation may be only half that which is obtained when two generous steam openings are employed.

35 Table 2 is intended to show the real advantage of coils. The figures presented are obtained from a number of kettles and coils in actual operation. It is seen that as the capacity of the kettle increases the heating surface per unit of contents decreases, which is not true of the coil, the reason being that the jacket surface of the kettle increases with the square of its linear dimension, whereas the volume increases as the cube.

PROCESS KETTLES

36 The last item to be considered is the process kettle. In one way this is perhaps the most important of all, since the success of the pack depends upon the process kettle. Its whole function is to raise the temperature of the contents of the cans to that necessary for sterilization. Fig. 9 is a diagrammatic representation of a process kettle.

37 There are four methods in use in the operation of these units: First, the cans are placed in the process kettle, which is previously empty; the kettle is then closed and steam turned on so that a pressure of between 5 and 15 lb. gage is secured. Second, this same process may be used, except that the kettle is previously filled with hot water and the cans are subjected to a water bath under pressure at a correspondingly high temperature. Third, the cans may be placed in a closed process kettle and subjected to a pressure very slightly greater than atmosphere, say, 1 lb. gage, there being no water in the kettle. Fourth, the process may be under atmospheric pressure but in a water bath with the lid of the kettle raised. These processes may be referred to as dry and wet, respectively, and closed and open.

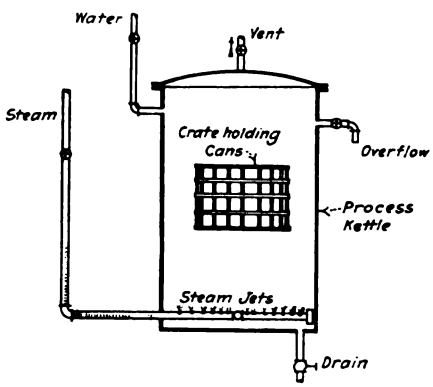


FIG. 9 PROCESS KETTLE

38 In the open-bath process it is a custom of operators to maintain a violent boil of the bath so as to secure a circulation through all the interstices between the cans, which practice results in large volumes of steam being emitted into the packing room. In the closed process it is the custom to vent the valve on top of the kettle. When the process is wet, it seems that the object is twofold: first to secure a circulation through the interstices, and second, because it is easier to maintain a uniform temperature with the steam flowing through rapidly with this vent valve considerably open than to secure this uniform temperature with only a small vent.

39 Now, besides raising the temperatures of the cans, in the dry process heat has to be furnished to the kettle in the following directions, all of which is wasted:

a To raise temperature of the metal of crates and kettle
b To vent the kettle, allowing air to escape, or to establish a circulation through the cans
c Condensed steam drained from kettle
d Radiation of heat from the outside surface of the kettle.

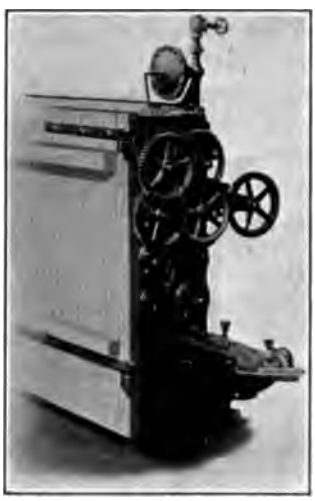
To these items must be added, when the wet process is used, the heat necessary to raise the temperature of a mass of water as well as that of the cans. Table 3 gives some quantitative values, obtained in part by test, but for the most part by calculation upon the assumption of reasonably good conditions in each item. In this connection it should be remembered that radiation, venting and overflow wastes may each vary widely with different operators and units.

TABLE 3 AMOUNT OF HEAT (B.T.U.) REQUIRED FOR PROCESSING IN ONE KETTLE 40 IN. IN DIAM. BY 72 IN. DEEP

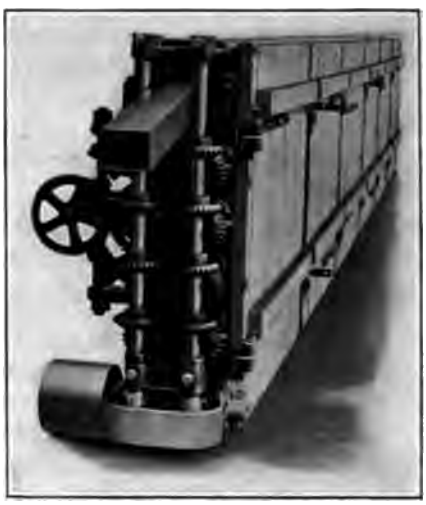
	½-hr. closed process at 240 deg. fahr.		1-hr. process Closed	1-hr. process Open
	Dry	Wet	Dry, 216 deg.	Wet, 212 deg.
To cans, from 120 deg.	198,000	198,000	158,000	152,000
To water, from 212 deg.	0	28,000	0	0 (?)
To metal, from 212 deg.	3,300	3,300	500	0
To vent on top	0+	17,500	0+	35,000+
Radiation	9,000	9,000	15,300	14,800
Overflow, or drain	38,000	46,000	26,000	29,300
Total B.t.u.	248,300	301,800	199,800	231,100
Boiler hp.	14.8	18.0	6.00	6.90

40 In studying the data presented in Table 3 it should be remembered that the calculations depend largely upon assumptions which are only approximately true, and furthermore that the conditions may vary widely so as to alter the figures. They show, however, what may be taken as a reasonably representative comparison. The first item, namely, the heat added to cans, assumes that the average temperature of the cans leaving the exhaust box is 120 deg.; the actual temperature may be greater or less than this. The further assumption is made that the contents of the cans are raised from this initial temperature up to the temperature of the process. Actually, the temperature of the process may be attained on the outside layers of the can, but this gradually merges to a lower temperature at the center, so that the average temperature at the finish

of the process is something less than 240 deg. in the closed process and less than 216 deg. in the open. The second item, having to do with the heat added to the water in the wet process, assumes this water to be at 212 deg. It may, however, be cooler if there is much



Feed End



Discharge End

FIG. 10 CONTINUOUS COOKER WITH AGITATOR

time between batches, allowing cooling, or if the operators introduce a large volume of cold water in the kettle to reduce the temperature quickly.

41 The same reasoning applies to the heat added to the metal of the process kettle and crates. The amount of steam vented from

the top of the kettle may vary considerably according to the custom of the operator. From tests made by the writer, with the closed process it amounts to the equivalent of 1 boiler hp. under the manipulation of a fairly careful operator. The radiation loss is less in total for the closed process than for the wet, since this is quicker, but the loss per square foot per hour is higher for the closed process, since the temperature difference is higher. The overflow or the drain loss may be much larger than quoted in the case of careless manipulation. It will be seen that the closed, dry process at 216 deg. is the most economical in the use of steam. Comparing the boiler hp. required for the different systems, it is noticed that the closed wet process takes about three times as much steam as the dry at 216 deg. On the other

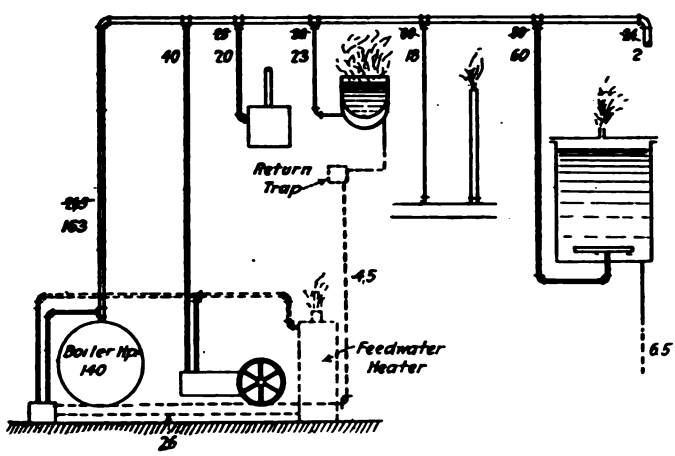


FIG. 11 IMPROVED STEAM DISTRIBUTION

hand, the former is capable of twice the capacity of the latter, so that the proportion of steam per can used is as 3 is to 2.

42 Efforts have been made to increase the capacity of process kettles by agitating the cans during cooking, machines for this purpose being styled "continuous cookers." Fig. 10 is one of recent design, and possesses some excellent features.

43 There seems to be ample field for enlightenment by experiment in the case of process kettles. Among the questions to be answered are: What are the times necessary to elevate the temperature of the center of a can under the open or closed systems, and how much difference is made by circulating water instead of steam upon the time? What effect has venting the kettle different

amounts? What effect has agitating the cans? If such venting of the kettles has any favorable effect, how may the steam thus lost be recovered? How does the temperature of the cans at various parts of the kettle vary? Of what value are automatic regulators to steam economy?

POSSIBILITIES OF IMPROVING PERFORMANCE OF PLANT

44 Referring to Fig. 11, the possibilities of bettering the performance indicated by Fig. 1 are shown. The consumption of the scalder is reduced from 25 to 20 boiler hp. by careful supervision of its performance. The efficiency of the jacketed kettle is improved by means of the return trap which passes back to the boiler 4½ boiler hp., thereby eliminating all possibility of waste in steam through the drain. The exhaust box is increased in efficiency to 50 per cent, and very probably much better than this can be secured with the more modern forms of exhaust box, the loss then largely being due to radiation. By using the dry process at 216 deg. the process kettle loses heat only through radiation in amount equal to about 5 boiler hp. and through condensate from the drain equal to about 6½ boiler hp., the loss through the vent with automatic regulation being negligible. It is questionable how the 6½ boiler hp. escaping from the drain may be utilized. It might be returned to the boiler as feed if provision were made to eliminate impurities. An exhaust-steam feedwater heater is added, by means of which 26 boiler hp. is recovered, but as the exhaust steam is in excess of the requirements for preheating the feed water, some of that available from the engine is lost through the vent. It is very possible that this excess of steam should be recovered in one of the steam-using units; for example, if a process kettle were designed with sufficiently large steam pipes and openings, exhaust steam could be used in it, or this exhaust steam could be used in a vacuum pan. There are a number of such possibilities.

GENERAL CONSIDERATIONS

45 Having now taken up in more or less detail the various familiar steam-using units in the canning factory, the writer would conclude with a few remarks of general application. Economy in steam means three things: increasing efficiency of units, eliminating all avoidable wastes, and utilizing all other wastes of heat as by-products. The first two can only be accomplished through meas-

urement — it is necessary to know *how much* steam is used and wasted. The packing house should be properly equipped with measuring instruments for this purpose. The familiar and little appreciated pressure gage is almost a stranger in the packing house, and yet a judicious use of this instrument will disclose much valuable information as to how steam is being used or abused. To find out how low the steam pressure is on some units whose inefficiency or lack of capacity has been ascribed to other causes and inspired futile remedies, will open the eyes of the superintendent. Next, when we eliminate wastes, we must eliminate *all wastes*, and not tolerate any just because we have been accustomed to seeing them and know that they are difficult to avoid. Wherever steam shows in the atmosphere it represents a waste, whether the steam comes from the jacket of a kettle, the vent of a process retort, the flue from an exhaust box or heater or scalder, or from any cause whatsoever. We have no right to discharge steam into the atmosphere, even if it is exhaust steam. We have no right to *radiate* heat to the atmosphere which might be saved by non-heat-conducting protection, and such wastes, it is necessary to say, are wantonly committed in the packing house. No steam-using units the writer has seen in such houses make the slightest provision against loss of heat by radiation. This is not only a waste of coal but a waste of human energy, since the operators cannot work efficiently in the torrid heat usually prevailing and aggravated by radiation from steam-using units. The packer objects on the ground of expense, but he should remember that each square foot of surface with steam behind it radiates to the atmosphere in ten hours an amount of heat requiring the burning of 1 lb. of present-day coal, and then, upon calculating what this aggregates to, will he realize that it is not a question of the expense of installing pipe coverings and other similar devices, but the expense of not doing so.

46 Finally, the question of how to utilize by-product heat requires careful study. In each factory the problem may be different, and in each it may be a separate case of proportioning the units to fit into each other. Feedwater heaters, traps, low-pressure heaters — all should be considered. Even the water used for cooling the cans, which carries away all of the useful heat transmitted, as previously defined, may be made to render up some of the heat it has removed.

when, due to the flotation effect particles of scum would come up. These would float on the top of the liquid and the operator would draw them off to one side and continue the operation until he got rid of them entirely; then he would shut off the steam and open the valve wide, when violent ebullition would start; but there was no foam. The loss of material from spraying, caused by violent ebullition, was overcome by using a properly designed separator, of which there were a number of good ones available.

He had found that a 4-in. coil would operate much better if the length was not over 25 or 30 ft., and that coils 30 ft. long would actually do twice as much work per square foot of coil surface as coils 60 or 75 ft. long. In the sugar industry it was sometimes necessary to use large coils. In such cases the coils were split up to get a number of sections — such would be the case in a very large vacuum pan. The evaporation taken from the tomato juice was an excellent solvent and therefore would cleanse well. His concern had dissolved calcium sulphate scale by the use of such distilled water. By treating $\frac{1}{16}$-in. solid gypsum scale with distilled water for six hours and boiling the water, the scale was dissolved.

In regard to Mr. Foster's suggestion, he would say that tests had shown that it made little difference whether saturated or superheated steam was used as far as increasing the capacity of the equipment was concerned.

L. B. McMillan mentioned the use of steam traps, which will let the air out and hold the steam back and thus hold the vessel temperature without the loss of steam. It seemed to him that proper insulation could be applied to apparatus that would pay for itself in such a short time that it would be advantageous to use it.

The Author. Referring to Dr. Bigelow's comments in regard to heat insulation, the canning factory presents a more special problem in the way of heat insulation for the reason that cleanliness is necessary. The mechanical problem can be solved, possibly, with air spaces of metal walls, but it has not been worked out because the canner has not taken enough interest in it up to date.

I am aware that evaporators, especially sugar evaporators, have been brought to a refined state of design. In the canning industry they have not. That is, special vacuum pans that are applicable to the canning industry have not been developed in the same way

that they have in the sugar industry. I believe there is a big future for vacuum pans for the reason that they can make use of exhaust steam. One large company has put in the most refined type of vacuum pan to boil down and concentrate the tomato juice which had been thrown away heretofore because it did not pay to bother with it. Now the cost of raw material has increased so that it will pay to evaporate the raw juice and get the solids out of it. Incidentally, because the evaporators are vacuum pans, waste steam is being used economically.

When I use the word "evaporator" in connection with foaming, I refer not only to vacuum pans but to all other types of evaporator —jacket kettles and coils. I should like to have more facts on this question of tomato pulp, because one difficulty encountered is the cooking of the pulp on the tubes, making it very difficult to clean them.

There is a possibility in the use of superheated steam, but little is known about its behavior in this industry. A small steam-inlet pipe connection is often used in canning apparatus, and the result is a large pressure drop; instead of 100 lb. there may be only 50 or 25 lb. in the apparatus. If the stream is initially wet, it will probably be wet at the lower pressure, with correspondingly low temperature. If initially superheated, the temperature at the lower pressure would be higher than that due to saturation, which would assist heat transfer.

No. 1638

MOISTURE REABSORPTION OF AIR-DRIED DOUGLAS FIR AND HARD PINE AND THE EFFECT ON THE COMPRESSIVE STRENGTHS

By Irving H. Cowdrey,[1] Cambridge, Mass.
Non-Member

Under ordinary atmospheric conditions air-dried timber quickly reabsorbs moisture and undergoes certain changes in its characteristic properties.

In order to determine how much greater would be the response and the consequent change in properties if the timber were introduced into a saturated atmosphere at a reasonably high temperature or if completely submerged in water, a series of investigations was conducted during the past year at the Massachusetts Institute of Technology on two important structural timbers — Douglas fir and southern hard pine. These tests are described in detail in the paper and the results obtained presented in the form of graphs.

While these tests were made on a limited number of small specimens and the results are confessedly comparative and qualitative rather than quantitative, the author is nevertheless of the opinion that an analysis of the data given will justify the following statements:

In the air-dry condition with approximately equal moisture contents the compressive strength of hard pine is about 25 per cent greater than that of Douglas fir.

When exposed to air saturated with water vapor at 120 deg. fahr., and when immersed in fresh water at 70 deg. fahr., the moisture reabsorption of air-dried fir is greater and more rapid than that of pine.

The temperature effect on strength decrease is of more importance on pine than on fir.

Pine shows a more rapid decrease in strength with the moisture increase than does fir. (The more rapid reabsorption by fir tends to offset this effect when the time element is used as a basis, so that for a given time of treatment the pine remains the stronger although the strengths tend to approach each other with more extended treatment.)

For moisture contents above 11 per cent when due to reabsorption from air saturated at 120 deg. fahr., the fir is stronger in compression than the pine. The same relation appears for moisture contents greater than 20 per cent when due to soaking in fresh water at 70 deg. fahr.

[1] Department of Mechanical Engineering, Massachusetts Institute of Technology.

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

THE effect of moisture on the properties of timber has become a well-established and recognized fact. Every practical man, whether he be an engineer or a craftsman, knows full well that the removal of moisture from timber, or the so-called "seasoning," produces marked changes in its strength, hardness, stiffness, resiliency and other characteristic properties. Much has been done in the way of scientific investigation by the Bureau of Forestry, The Forest Products Laboratory and various universities and technical schools to determine the effect of the progressive removal of moisture on the strength of timber of all kinds.

2 The results obtained have appeared with lengthy discussions in the bulletins[1] and technical papers issued by these bodies and in the proceedings of various professional societies. In view of this, it were a waste of time and effort to present such data and such discussion in this paper.

3 To the reversal of this process there has been given considerably less attention. There is often expressed great surprise at the rapid and very appreciable regain of moisture by wood after it is removed from the dry kiln. This reabsorption, moreover, is not confined to kiln-dried wood, but occurs as well in the case of timber which has been thoroughly air-dried. In fact, the reabsorptive power of air-dried timber is believed to be somewhat greater than is that of timber which has been properly and thoroughly kiln-dried.[2]

PROBLEMS TO BE SOLVED

4 If, then, wood responds so quickly in its reabsorption of moisture under very ordinary atmospheric conditions, and in consequence thereof undergoes change of properties, how much greater will be the response and the consequent change of properties if the timber be introduced into a saturated atmosphere at reasonably high temperatures, or if it be completely submerged in water?

5 A recognition of the importance of these items and the belief that reabsorption is a factor to be reckoned with has led to the conducting of a series of investigations during the past year in the Testing Materials Laboratory of the Massachusetts Institute of Technology to determine the quantitative effect, if possible, of such

[1] Notably in Bulletin No. 70 of the U. S. Dept. of Agriculture, by H. D. Tiemann.

[2] Bulletin No. 70, U. S. Dept. of Agriculture, treats of the effect of reabsorption of certain woods from the kiln-dry condition, but does not consider the effect on air-dry wood, nor on Douglas fir under any condition.

conditions. Moreover, during the past few years the eastern lumber markets, as typified by Boston, have witnessed the entrance of a new competitor in the field of structural timber, namely, *Pseudotsuga Douglasii.*

6 This fact led the experimenters to make a parallel investigation for the purpose of comparing this Douglas fir with the better-known southern hard pine, which has been so long established in the structural engineering of this part of the United States. In so far as the writer is aware, this is the first work of the kind to have been done on Douglas fir. The pine used falls under the classification of "dense southern pine" according to the standards of the American Society for Testing Materials and is very probably the long-leaf yellow pine (*Pinus palustris*).

NATURE OF THE INVESTIGATION

7 The investigation under discussion may be briefly outlined as follows: The stock used had been purchased in the open market without any special care in selection. In the form of 4-in. planks it remained in the testing laboratories about six months under the conditions of heat and moisture ordinarily pertaining to such localities, being open to free and complete circulation of air over and around the material.

8 Tests showed the moisture content to be between 6 and 8 per cent for all pieces. The timber, then, may be considered to have been thoroughly air-dried. From these planks were cut specimens which were planed to a section 2 in. by 2 in. and 20 in. long. These pieces were cut further into blocks 8 in. long, and the pairs thus obtained were used in most cases under similar conditions of treatment for check purposes. All treatments were conducted on specimens 8 in. long and tests were made on specimens 6 in. long formed by the removal of 1 in. from each end of the treated specimen.

9 A number of specimens of both pine and fir were tested in the air-dry condition to establish their initial properties. One set consisting of 20 pieces of pine and 20 pieces of fir was subjected for various lengths of time to a saturated atmosphere at 120 deg. fahr. Another similar set was immersed in fresh water at 70 deg. fahr. for various periods of time. The relative rates of moisture penetration and the properties of the wood as determined by direct compression in a direction parallel with the grain were investigated and the results appear later in this discussion.

10 The moisture determinations were made as follows: From the blocks were cut sections approximately $\frac{1}{4}$ in. thick. (The cutting lines were laid off at $\frac{1}{4}$-in. intervals and the saw scarf then reduced the thickness to about $\frac{3}{16}$ in.) Six of these were cut from the first $1\frac{1}{2}$ in. of length and a seventh from the center. See *A*, Fig. 1. It was necessary to eliminate the effect of lateral penetration of moisture, consequently the outer $\frac{1}{4}$ in. was removed from these sections with a chisel, as indicated at *B*, Fig. 1.

11 The moisture content was obtained in the usual manner. After removal of all adhering dust and splinters, the sections were carefully weighed. They were then exposed to a reasonably dry air bath at 212 deg. fahr.

12 The drying is continued until a "constant weight" is obtained. With samples of this size and form, taken from the woods under consideration, this constant weight is generally obtained in about $1\frac{1}{2}$ hours. This is known as the "oven-dry weight."

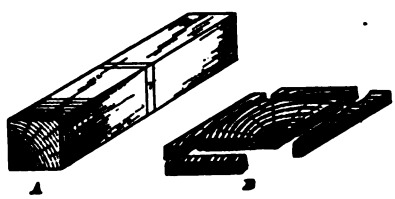


FIG. 1 METHOD OF CUTTING SPECIMENS

13 The *loss in weight* under the above conditions, divided by the oven-dry weight, expressed as per cent, gives the moisture content.

14 In any discussion dealing with the effect of moisture on the characteristics of wood it is very essential to have in mind the form in which water may exist in the cellular structure.

15 The water present in wood may exist (*a*) as free water within the cellular spaces, the canals and ducts, and possibly to some slight extent in the intercellular cavities; and (*b*) as water which has been actually absorbed by the material which constitutes the cell walls. It is commonly supposed that the absorption of water from moist air at least is first an absorption by the cell walls, and that later under some conditions there occurs a partial filling of the cell cavities. The maximum water content possible without the presence of free water in the cells and canals is known as the "fiber-saturation point." When water is absorbed because of the actual immersion of the wood

it is very likely that free water may exist in the cells without the cell walls having absorbed a quantity sufficient to produce fiber saturation. For most of the more common timbers this fiber-saturation point occurs at a moisture content of approximately 25 per cent.

16 Most writers consider that it is only this second form, or "imbibed" water, as it is sometimes called, which affects the strength. No satisfactory theories have been advanced to elucidate the phenomenon. Whether the action is purely physical or whether it may partake of a certain chemical semblance is a point of some disagreement. It would seem to the writer as though perhaps there may occur some of the effects of colloidal solution. This last suggestion might to some extent be borne out by the fact that a very complete kiln-drying at high temperature prevents or markedly decreases certain effects commonly produced by reabsorption of moisture such as swelling, increase of pliability, etc.

17 Again, the writer would hold that the free water in the cells and canals may also have a weakening effect, due to re-solution of some of the salts which are undoubtedly deposited within the cells as the sap dries out, or in the case of heart wood by infiltration during the life of the tree. These crystalline deposits, it would seem, must have a stiffening effect, and, if present in sufficient quantity to fill completely the cell or to bridge it at any point, should add quite materially to the rigidity of the cell, as latticing adds to the rigidity of structural compression members.

RELATIVE RATES OF MOISTURE PENETRATION LONGITUDINALLY

18 Only the rate of penetration in the direction of the fiber was investigated. The specimens, in the form of blocks 2 in. by 2 in. by 8 in. were subjected to the desired treatment for periods ranging from one hour to 117 hours. At the end of the period of treatment the moisture content was obtained as previously described.

19 While the relative behaviors of the pine and fir show certain points of similarity with regard to their reabsorption from both saturated air and from water, yet certain details are sufficiently variant to warrant a separate discussion.

20 *Reabsorption When Exposed to Saturated Air at* 120 *Deg. Fahr.* The specimens were treated by placing them on a grid just above the surface of hot water in a covered steamer freely vented to the air. It was found possible to maintain the temperature of the vapor in the

steamer within the limits of 2 deg. fahr. variation during the longest period of treatment, namely, 24 hours.

21 Fig. 2 shows the reabsorption of the specimens during periods of 1, 3, 9, and 24 hours of treatment. The curves take a hyperbolic form and it will be noted that in every case except that for the 1-hr. treatment the reabsorption by the fir is much in excess of that by the pine. It has seemed best to plot the reabsorption in terms of the

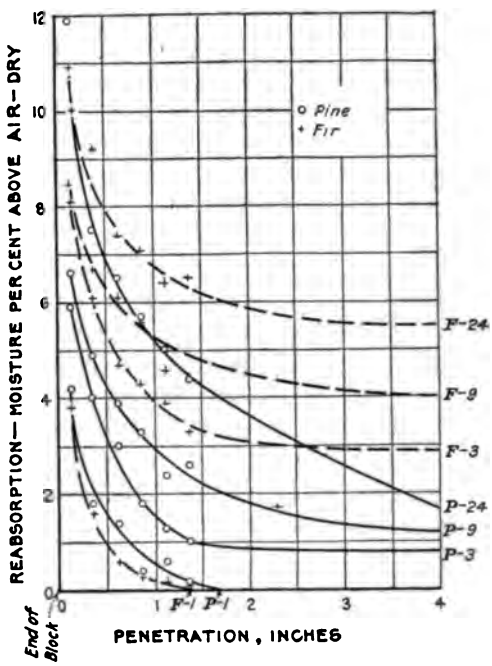


FIG. 2 REABSORPTION OF SPECIMENS WHEN EXPOSED TO SATURATED AIR AT 120 DEG. FAHR.

P-1 indicates pine treated 1 hr.; *F-9* fir treated 9 hr.; other symbols to be similarly interpreted

moisture content in excess of that present in the air-dried condition rather than the absolute moisture content. This was done to eliminate if possible any variation of hygroscopic action inherent in the specimen due to structural peculiarities.

22 Referring to curves *P-1* and *F-1* representing the conditions at the end of an hour's treatment, it will be noticed that no reabsorption was manifest beyond a point approximately 1½ in. from the end. The curves *F-3* and *P-3*, showing the effect of 3 hours'

treatment, clearly indicate some absorption, even at a distance of 4 in. from the exposed end grain. This furnishes a very striking example of the extreme rapidity with which moisture will penetrate along the grain of timber when it is exposed to the action of hot, moist air.

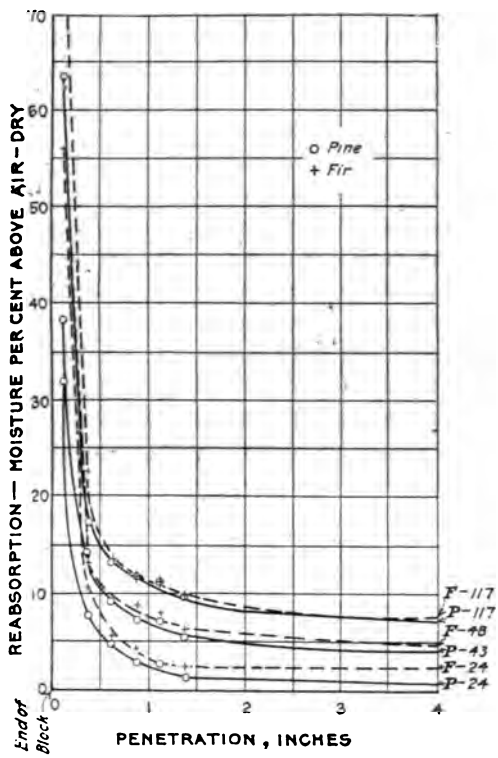


FIG. 3 REABSORPTION OF SPECIMENS WHEN COMPLETELY IMMERSED IN FRESH WATER AT 70 DEG. FAHR.

P-24 indicates pine treated 24 hr.; *F-48*, fir treated 48 hr.; other symbols to be similarly interpreted

23 It should be noted that in none of the treatments did the reabsorption become greater than 12 per cent average moisture in the first $\frac{1}{4}$ in. from the end. With the air-dry condition of 8 per cent of moisture or less, giving a total moisture of 20 per cent or less, it would seem that the fiber-saturation point was not attained. However, the point plotted represents the average only for the first $\frac{1}{4}$ in., and as the plots show, the moisture content decreases very rapidly at

first; hence it seems fair to presume that the walls of the cells immediately adjacent to the surface may have reached the point of saturation. From this it might be inferred that saturated air at 120 deg. fahr. is capable of producing fiber saturation. It seems also reasonable to suppose that if the treatment were continued for a period of sufficient length this condition might extend throughout the timber regardless of size. The logical conclusion to be drawn from this leads to the statement that *timbers subjected to the action of saturated air at* 120 *deg. fahr. must be designed on a basis of constants determined from tests on green timber.*

24 *Reabsorption When Completely Immersed in Fresh Water at* 70 *Deg. Fahr.* The specimens in this series were treated by immersion in a tank of water in which continuous renewal was maintained at such a rate that an entire change was effected at least once each 24 hours. Temperature regulation was arranged to keep the water at 70 deg. fahr.

25 Reabsorption tests were made at the end of 1, 24, 48, 72 and 117 hours. The observations were all concordant and hence only the data obtained from the 24-, 48- and 117-hour periods have been plotted in Fig. 3. Here the relative reabsorptive powers of pine and fir are much more nearly alike than in the case of the treatment in saturated air. Yet even here it will be noted that in all cases the reabsorptive power of the fir is slightly greater than that of the pine.

26 The effect of capillarity will almost immediately fill the open-ended cavities of the cells and canals at the exposed surface of an immersed stick. Hence the first quarter inch shows a total moisture content, even after a single hour's immersion, far above that necessary for fiber saturation. (Data not shown in Fig. 3.) This, however, does not indicate the speed at which fiber saturation is actually attained, and since there seems to be no means of differentiating the two conditions of included moisture, such a determination does not seem possible.

27 While the time required for fiber saturation is not definite in the case of timber immersed in water, yet an inspection of the curves of Fig. 3 shows clearly that such saturation undoubtedly occurs and that it is only a matter of time whether in the case of columns or beams of timber, even though previously air-dried, for them to be reduced to the character of green wood. It would seem, then, that conclusions relative to the design of timber liable to submersion are similar to those drawn in Par. 25 at the close of the discussion of the effect of treatment by saturated air.

28 *Comparison of Figs.* 2 *and* 3 beyond the first half inch from the exposed end shows that the rapidity of reabsorption is much less when the wood is immersed in water at 70 deg. fahr. than when exposed to air saturated at 120 deg. fahr. In detail it will be noted that 24 hours in water are required to produce approximately the same reabsorption as 3 hours' treatment in moist air, and that the reabsorption after 48 hours' submersion is approximately that attained during a 24-hour exposure to moist air.

EFFECT OF REABSORPTION ON THE COMPRESSIVE STRENGTH

29 As previously noted, the blocks under investigation were treated in the form of specimens 2 in. by 2 in. by 8 in. After treatment a section 1 in. thick was removed from each end, thus giving a specimen 6 in. long for the compression tests. The ends were squared in a metal miter box so that the faces subjected to pressure were as nearly parallel as possible. The failure of the specimens would indicate a pure compression stress.

30 After failure a quarter-inch section was removed from the specimen at the point of fracture, and from this the moisture content was obtained as previously described.

31 Figs. 4 and 5 have been prepared to show the relations, if any exist, between the actual moisture content and the crushing strength of the two woods under discussion.

32 All of the fir tested, with two exceptions, showed from 12 to 17 rings per inch measured radially. Of these exceptions one showed 10 and the other 20 rings per inch. The summer wood comprised from 30 to 60 per cent of the total growth, about one-half the total number of specimens containing between 40 and 50 per cent of summer growth. The air-dry density ranged between 31 and 36 lb. per cu. ft.

33 The pine under investigation (with the exception of three specimens noted later and marked *S* on Fig. 5) showed from 7 to 10 rings per inch measured radially. The summer wood ranged from 30 to 50 per cent of the total growth, except in specimens *S*. The air-dry density, except for specimens *S*, was between 32 and 36 lb. per cu. ft.

34 Specimens *S* (three in number, see Fig. 5) had but 6 rings per inch, showing only 25 per cent of summer wood, and had an air-dry density of about 30 lb. per cu. ft. It is evident that the wood from which these were cut should be classed as "sound" rather than as "dense" southern pine according to the A. S. T. M. standards.

35 The moisture-strength relations for the fir and pine will now be taken up separately and later compared.

36 *Douglas Fir* (see Fig. 4). The most superficial glance at the plotted data will very clearly show that the compressive strength of the wood falls as the moisture content increases. While mathematical methods are possible in the establishment of such a curve, such a method of investigation seems hardly warranted in this instance. The curve drawn is assumed by the writer to be fairly representative and is at least indicative of certain fundamental relations.

37 The data were obtained as previously explained from tests made on specimens subjected to radically different treatments. In

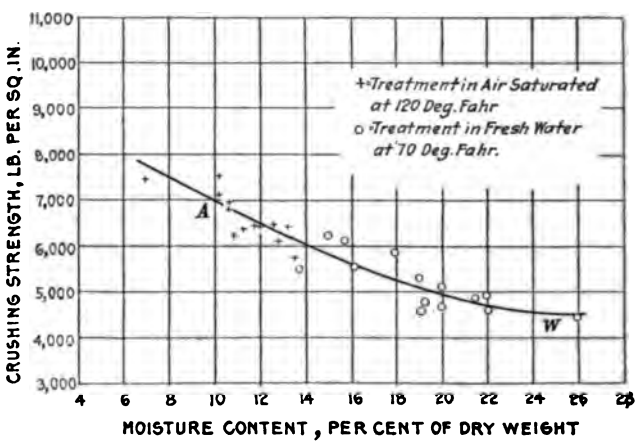


FIG. 4 RELATION BETWEEN MOISTURE CONTENT AND CRUSHING STRENGTH OF DOUGLAS FIR

the case of the fir, nevertheless, the resulting graph is evidently a continuous line. The inclination is somewhat sharper with the lower moisture contents and flattens out, becoming approximately horizontal at a moisture content of about 25 per cent. This corresponds very closely with the fiber-saturation point previously referred to and would seem to bear out the existing theory that only the "imbibed" moisture affects the strength in compression.

38 While it must be kept in mind that the values of the strengths here recorded are in no way indicative of the proper constants for use in design, yet it is felt that certain of the relations apparent are of fundamental truth. It will be noted that the treatment of wood by exposure to air saturated at a temperature of 120 deg. fahr. results in

a compressive strength of about 25 per cent less than the strength of air-dry timber. This reduction appears at about 14 per cent moisture content.

39 Submersion in water at 70 deg. fahr. for a period of 117 hours produces at the point of fracture a moisture content of 26 per cent, thereby reducing the strength to a value about 40 per cent below that for air-dry wood of the same quality.

40 *Yellow Pine* (see Fig. 5). The data recorded in Fig. 5 offer certain marked variations from those shown for fir in Fig. 4, the curve for which has been transposed to this plot as a dash line. It is very obvious that the data obtained from the pine yield plotted points which cannot be satisfactorily represented by a single line. The

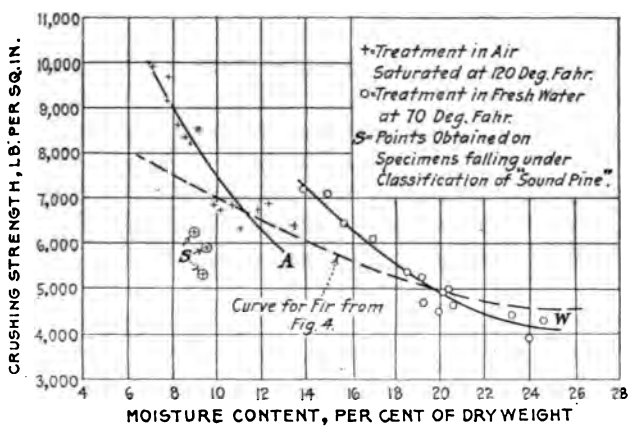


FIG. 5 RELATION BETWEEN MOISTURE CONTENT AND CRUSHING STRENGTH OF YELLOW PINE

data from the water-soaked specimen, marked *W*, yield a fairly determinate curve. The data from the specimens exposed to the moist air, marked *A*, might be reasonably well represented by a variety of lines. However, it seems fair to presume that the two lines will be of the same general type even though they are discontinuous. Such has been the assumption used as a guide in drawing the representative lines.

41 The generalizations for the pine are quite similar to those drawn from the graph characteristic of the effect of reabsorption by the fir. The decrease in strength is at first quite rapid with the increase of moisture content. It later flattens, becoming nearly horizontal at about 25 per cent moisture content, again indicating this value as the fiber-saturation point.

42 The rate of decrease in strength seems to be more rapid for yellow pine than for fir. In the case of the specimens investigated this decrease becomes about 35 per cent after 24 hours' exposure to air saturated at 120 deg. fahr. It is only fair to suggest that this decrease may not be due entirely to moisture, which point is discussed in Pars. 47–49.

43 Due to the extremely rapid reabsorption, no points were obtained for the soaked specimens between the air-dry condition and about 14 per cent of moisture. The graph *W* as drawn, however, if extrapolated as a straight line will pass very close to the data obtained from the air-dry material. This graph shows that the moisture content of about 25 per cent which was present 1 in. from the exposed end after a soaking of 117 hours, resulted in a strength nearly 60 per cent below the strength of the air-dry material.

44 *Reasons for the Discontinuity of the Graph.* The wood treated in the moist air at 120 deg. fahr. was tested immediately upon removal from the steamer. It was warm when subjected to pressure; in some cases the temperature of the inner portions was probably at least 100 deg. fahr. Pine is a very resinous wood. At the temperatures maintained this resinous material will soften, and some of the normally solid constituents will undoubtedly become actually liquefied. The portions normally in the state of a liquid of high viscosity will undoubtedly have their viscosity considerably lowered. The effect of this action will be that of a general removal of the stiffening action of the cell contents and a possible lubricating effect tending to permit a greater freedom of movement between cells which are poorly adherent because of incidents of growth. This effect is additive to the general effect of the absorption of moisture and may well explain the sharp pitch of the curve *A*.

45 The temperature of the water (70 deg. fahr.) used for the soaking treatment is probably insufficient to produce the above-noted effect. In fact, the temperature is approximately that at which the air-dry specimens were tested. It would seem, then, that the temperature factor may reasonably be eliminated from a discussion of the curve *W*. If such be the case, it is to be expected that a given moisture content when obtained in the water at 70 deg. fahr. will show a less-marked weakening effect than does the same moisture content when resulting from exposure to moist air at 120 deg. fahr. Observing the conditions at a moisture of 14 per cent, such is found to be the case. The difference between the ordinates of curves *A* and *W* at this degree of saturation may well be taken to represent the weaken-

ing effect of heat due to softening of the resinous compounds by a heating for 24 hours at 120 deg. fahr.

46 Since the quantity of resinous matter in the Douglas fir is much less than that in the pine, this temperature effect would doubtless be absent and the resulting graph be a continuous curve, as was found to be the case.

47 The specimens giving the points marked *S* are of considerable interest as an exemplification of the fact that wood of coarse growth, low percentage of summer wood and corresponding lesser density yields a lower compressive strength than when the reverse conditions obtain. Though the number of pieces coming in this category is small, yet the facts point strongly toward a justification of the acceptance of the so-called "density rule" of the standards of the American Society for Testing Materials.

COMPARISONS AND GENERAL CONCLUSIONS

48 In the interpretation and subsequent use of the data furnished in this paper, it must be kept in mind that the specimens tested were bought in the open market of Boston; that no special selection of material was made except so far as was necessary to obtain specimens of reasonably straight grain, free from knots and serious defects; that tests were made on small specimens, limited in number and selected from a very small initial quantity of lumber; that in consequence of the above facts the results must be considered comparative and qualitative rather than definitely quantitative.

49 With all the above in mind, an analysis of the preceding data as shown by the accompanying plots seems to justify the following statements:

In the air-dry condition with approximately equal moisture contents the compressive strength of hard pine is about 25 per cent greater than that of Douglas fir.

When exposed to air saturated with water vapor at 120 deg. fahr. and when immersed in fresh water at 70 deg. fahr. the moisture reabsorption of air-dried fir is greater and more rapid than that of pine.

The temperature effect on strength decrease is of more importance on pine than on fir.

Pine shows a more rapid decrease in strength with the moisture increase than does fir. [The more rapid reabsorption by fir tends to offset this effect when the time element is

used as a basis, so that for a given time of treatment the pine remains the stronger although the strengths tend to approach each other with more extended treatment.]

For moisture contents above 11 per cent when due to reabsorption from air saturated at 120 deg. fahr., the fir is stronger in compression than is the pine. The same relation appears for moisture contents greater than 20 per cent when due to soaking in fresh water at 70 deg. fahr.

No. 1639

A FOUNDRY COST AND ACCOUNTING SYSTEM

By William W. Bird, Worcester, Mass.
Member of the Society

In this paper the author outlines the foundry cost and accounting system which has been developed as a result of experiments carried on in connection with the commercial foundry at the Worcester Polytechnic Institute.

The system, it is stated, is giving good satisfaction, the results being fairly accurate and the comparative monthly data which it keeps before the foundry officials having been found to be thoroughly reliable as a signal system. All of the work involved can be done by the regular clerical force in a small amount of extra time, and the services of an expert accountant are not required.

THE work in Shop Management at the Worcester Polytechnic Institute is in the nature of a laboratory course, and experimental work in accounting and cost keeping is made possible by the commercial foundry and machine shop of the Institute, known as the Washburn Shops.

2 The object of this paper is to present an outline of the foundry cost and accounting system which has been developed as a result of the experiments carried on in connection with the commercial foundry at the Institute.

3 The first problem was to determine the number of independent variables and how the dependent ones were related to them. After several years of experimental work it was decided that the three most important items were Core Labor, Molding Labor, and Pounds of Castings Produced, and that each of the other items of cost was a function of some one of these three independent items.

4 Ledger accounts were opened for each one of the items, and by careful inventories at the beginning and end of each year the exact annual cost for each item was worked out.

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5 The next problem was to determine a proper production credit for the individual accounts for each month, based on factors secured by previous records. The general scheme being to charge an account with the amount of the purchases for that month and credit it with a fair estimate of what ought to have been used for that month's work. The ledger balance at the end of each month gives a book inventory for that account. These production credits are charged to another account, as will be explained later.

6 All expenses are charged to the Expense Account and the production credit for expense ought to be large enough to more than balance the charges, thus creating a balance to the good, known as Expense Reserve.

7 In other words, every ledger account is an exact record of costs for the year, while each monthly balance has a definite meaning.

CORE WORK

8 The material required for core work was found to average about 30 per cent of the core labor, hence to make the production credit for core work for a month it was only necessary to secure from the payrolls the amount paid to the core makers for that month and add 30 per cent for the supplies used. Unfortunately, this did not work well at first, as the payrolls are made out weekly and not monthly. It was decided that the proper period for the foundry records was once each month, as it was desired to tie it up with the regular accounting system, with its monthly trial balance. It was therefore necessary to start a split payroll system for all weeks having one or more days in two different months.

MOLDING

9 All of the items of cost in the foundry excepting the metal, melting and core work, were divided into two classes: Supplies, or all the materials used in connection with molding, such as sand, facing, etc., and Expense, or all charges for management, office work, power and other overhead items, cleaning, flasks, etc. For several years the expense account was subdivided, but it was found to be unnecessary for our foundry.

10 At the present time we are basing our production credits for supplies on 6 per cent of the molding labor and the expense on 75 per cent, the molding labor for the month being secured from the payrolls, all of the molders being grouped for this purpose.

METAL AND MELTING

11 In order to secure the exact tonnage for each month it was found necessary to make an inventory on the first of each month of the castings on hand. This, however, is only a close estimate of the weight of these castings. A record of the castings sold during the month gives the tonnage also. Correcting this for the change in the inventory of castings, gives the production in pounds for the month.

12 The cost of melting was found to vary directly with the pounds of castings produced, and therefore the melting production credit for the castings produced each month is found by multiplying the pounds produced by the melting factor, which at present is 30 cents per 100 lb.

13 A careful record for a number of years of the castings produced and of the pig and scrap used, gives the data for the factors to be employed in making up the production credits for the metal used each month. At present we use 75 per cent of the pounds produced as the proper weight of pig iron, and 37½ per cent for scrap iron. These factors take care of the shrinkage and the defective castings, as these are replaced without credit to the foundry.

14 Knowing the weight and cost of the pig iron purchased each month, this cost including all charges for freight and teaming, the cost per 100 lb. is made up. Multiplying this by 75 per cent of the pounds produced, we have the production credit for pig iron. The production credit for scrap iron is worked out in the same way.

15 The problem of handling the difference between the material purchased and what was actually used was solved by making the ledger balance a book inventory for material accounts and a reserve for the expense account, as stated.

16 The next problem of how to adjust the difference between the castings sold and the castings produced was solved as follows:

17 Two ledger accounts were opened — Foundry Sales and Foundry Production. The first is credited with the monthly sales and charged with the factor cost of the castings sold. The balance of this account is the factor gain and gives a definite line on the profits.

18 Foundry Production is charged each month with the total amount of the production credits and credited with the factor cost of the castings sold, the monthly ledger balance giving the value of the castings on hand. In fact, the value of the castings on hand is worked up first from the inventory made on the first of each month,

and the factor cost of castings sold is simply the amount required to make the account show the proper balance.

19 To show the exact working of this system, the figures for three months will be given — a good month, a fair month, and a poor one. As these months did not come in this exact order, it was necessary to make a few changes in the figures, but they are substantially an exact record.

20 Starting with a clear record on July 1, with no castings on hand, we have:

BALANCE SHEET, JULY 1

ASSETS		LIABILITIES	
Bills receivable	$13,187.20	Capital	$20,000.00
Cash	6,331.06	Surplus	3,654.13
Metal and supplies	1,333.03	Bills payable	2,197.16
Equipment	5,000.00		
	$25,851.29		$25,851.29

21 The inventory on August 1 gave 3500 lb. of castings on hand, the sales record gave 122,541 lb. sold, the production was therefore 126,041 lb. The core labor was $443.89 and the molding labor $1863.84. 117,180 lb. of pig iron cost $2381.86 and the scrap iron cost $1.50 per hundred delivered in the yard. These are all of the data necessary for making up the following:

MONTHLY FOUNDRY RECORD, JULY

Purchases	Division	Factor	Production credits
$ 443.89	Core labor	100%	$ 443.89
127.00	Supplies	30%	133.17
1,863.84	Molding labor	100%	1,863.84
156.29	Supplies	6%	111.83
1,303.03	Expense	75%	1,397.88
612.17	Metal — melting	30¢	378.12
2,381.86	117,180 lb. pig iron	75%	1,918.98
737.62	$1.50 per 100 scrap iron	37½%	708.98
$7,625.70	Total Factor Cost of Production		$6,956.69

22 The factor cost was $5.52 per 100 lb. for castings produced and the castings on hand at the end of the month were valued at this rate. 3500 lb. at $5.52 gives a correction of $193.20. This is the difference in the value of castings on hand at the beginning and end of July.

Factor cost of production	$6,956.69
Correction	193.20
Factor cost of castings sold	6,763.49
Sales for July	7,350.31
Factor gain for July	$586.82

23 The Expense Reserve is found by subtracting the charges $1303.03 from the credits $1397.88, giving $94.85 for the month.

24 The trial balance of the ledger gives the necessary data for the following:

BALANCE SHEET, JULY 31

ASSETS		LIABILITIES	
Bills receivable	$13,288.31	Capital	$20,000.00
Cash	6,299.50	Surplus	3,654.13
Castings	193.20	Bills payable	2,542.10
Metal and supplies	2,096.89	Expense reserve	94.85
Equipment	5,000.00	Factor gain	586.82
	$26,877.90		$26,877.90

25 On September 1 we had 4000 lb. of castings on hand, and sold in August 132,773 lb. The production was therefore 133,273 lb., as we had 500 lb. more on hand at the end of the month than at the beginning.

MONTHLY FOUNDRY RECORD, AUGUST

Purchases	Division	Factor	Production credit
$ 522.61	Core labor	100%	$ 522.61
45.50	Supplies	30%	156.78
1,968.90	Molding labor	100%	1,968.90
44.83	Supplies	6%	118.13
1,426.64	Expense	75%	1,476.67
382.21	Metal — melting	30¢	399.82
2,759.65	107,620 lb. pig iron	75%	2,568.84
701.70	$1.75 per 100 scrap iron	37½%	874.62
$7,852.04	Total Factor Cost of Production		$8,086.37
	Inventory correction		$ 49.60
	Factor cost of castings sold		$8,036.77
	August sales		8,179.51
	Factor gain — August		142.74
	Factor gain — July 1–Aug. 1		586.82
	Factor gain — July 1–Aug. 31		$729.56

26 The Expense Reserve for August is $1476.67 minus $1426.64, or $50.03, making the total Reserve, August 31, $144.88.

BALANCE SHEET, AUGUST 31

ASSETS		LIABILITIES	
Bills receivable	$14,016.50	Capital	$20,000.00
Cash	5,750.82	Surplus	3,654.13
Castings	242.80	Bills payable	2,394.14
Metal and supplies	1,912.59	Expense reserve	144.88
Equipment	5,000.00	Factor gain	729.56
	$26,922.71		$26,922.71

27 On October 1 we had 15,000 lb. of castings on hand and sold during September 124,557 lb. The production for the month was therefore 135,557 lb.

MONTHLY FOUNDRY RECORD, SEPTEMBER

Purchases	Division	Factor	Production credit
$ 542.00	Core labor	100%	$542.00
65.46	Supplies	30%	162.60
2,016.70	Molding lab r	100%	2,016.70
144.94	Supplies	6%	121.00
1,326.58	Expense	75%	1,512.53
541.90	Metal — melting	30¢	406.67
2,834.85	116,980 lb. pig iron	75%	2,460.37
1,763.52	$1.75 per 100 scrap iron	37½%	889.60
$9,235.95	Total Factor Cost of Production		$8,111.47

Inventory correction	$ 654.20
Factor cost of castings sold	$7,457.27
September sales	7,485.76
Factor gain — September	28.49
Factor gain — July 1–Sept. 1	729.56
Factor gain — July 1–Sept. 30	$758.05

28 The Expense Reserve for September is $1512.53 minus $1326.58, or $185.95, which added to $144.88 makes the total Reserve $330.83.

BALANCE SHEET, SEPTEMBER 30

ASSETS		LIABILITIES	
Bills receivable	$13,378.81	Capital	$20,000.00
Cash	5,374.27	Surplus	3,654.13
Castings	897.00	Bills payable	3,130.09
Metal and supplies	3,223.02	Expense reserve	330.83
Equipment	5,000.00	Factor gain	758.05
	$27,873.10		$27,873.10

29 In order to keep comparative data before the foundry officials and aid them in the analysis of the monthly records, the following table is filled in as soon as possible after the first of each month:

MONTHLY AVERAGES

	Previous year	July	August	September
Production, lb	138,605	126,041	133,273	135,557
No. of heats	24.5	24	24	25
No. of molder days	442	467	478	493
Weight per heat, lb	5670	5250	5550	5420
Wt. per molder day	314	270	279	275
Cost of molding	$1,644.82	$1,863.84	$1,968.90	$2,016.70
Avg. pay per molder day	$3.72	$4.00	$4.12	$4.09
Core work per 100 lb	0.42	0.46	0.51	0.52
Molding and expense	2.14	2.68	2.67	2.69
Melting and metal	1.53	2.38	2.89	2.77
Production cost	$4.09	$5.52	$6.07	$5.98
Inventory correction	.....	.....	0.02	0.01
Cost of castings sold	$4.09	$5.52	$6.05	$5.99
Selling price	$4.36	$6.00	$6.16	$6.01
Factor gain	0.27	0.48	0.11	0.02
Sales total	$6,093.60	$7,350.31	$8,317.51	$7,542.46
Factor gain month	$375.46	$586.82	$142.74	$28.49
Per cent gain	6.2	8.0	1.7	0.4
Expense reserve	$35.00	$94.85	$50.03	$185.95
Rating	Good	Good	Fair	Poor

30 In order to keep a line on the book inventories, the following table is filled in each month. These figures show the changes in the several accounts and indicate in a way how the factors are working. If an account is steadily growing, as the Pig Iron Account shows in this table, we are either accumulating pig iron or the factor is too small. Core Supplies here shows a constantly diminishing amount

and either we are reducing our supplies or the factor is too large. An exact inventory can be made at any time to check up the book inventory and a change made in the factor if necessary.

INVENTORIES — METAL AND SUPPLIES
MONTHLY CHANGES

	July	August	September
Core supplies	−6.17	−111.28	−97.14
Molding supplies	+44.46	−73.30	+23.94
Melting supplies	+234.05	−17.61	+135.23
Pig iron	+462.88	+190.81	+374.48
Scrap iron	+28.64	−172.92	+873.92
Net change	+763.86	−184.30	+1,310.43
Beginning of month	$1,333.03	$2,096.89	$1,912.59
End of month	$2,096.89	$1,912.59	$3,223.02

31 The following samples of ledger pages will show just how the bookkeeping is done:

FOUNDRY SALES

July 31	Factor cost — sales	$6,763.49	July 31	Sales	$7,350.31
	Balance	586.82			
		$7,350.31			$7,350.31
			Aug. 1	Balance	586.82

The balance of this account gives the Factor Gain and is the total amount from the beginning of the fiscal year.

FOUNDRY PRODUCTION

Aug. 1	Balance	$ 193.20	Aug. 31	Factor cost—sales	$8,036.77
31	Factor cost — production	8,086.37		Balance	242.80
		$8,279.57			$8,279.57
Sept. 1	Balance	242.80			

The balance on this account is the exact inventory of the castings on hand, valued at the factor cost for the month.

FOUNDRY EXPENSE

Sept. 30	Purchases.....	$1,326.58	Sept. 1	Balance.....	$ 144.88
	Balance.....	330.83	Sept. 30	Production credits	1,512.53
		$1,657.41			$1,657.41
			Oct. 1	Balance.....	330.83

The balance on this account is the amount that the Reserve has built up during the year.

PIG IRON

July 1	Balance.....	$ 331.20	July 31	Production credit.	$1,918.98
July 31	Purchases.....	2,381.86		Balance.....	794.08
		$2,713.06			$2,713.06
Aug. 1	Balance.....	794.08			

The balance on this account is the book inventory for the pig iron on hand.

32 Thus every ledger balance has a definite meaning, either an inventory, a reserve or a gain, and the complete balance sheet for each month can be made up in a few minutes from the regular trial balance. All of the work can be done by the regular clerical force and requires but a small amount of extra time. No expert accountant or efficiency engineer is needed.

33 The closing of the books at the end of the fiscal year introduces several interesting problems.

34 The Molding and Core Labor Accounts take care of themselves as the charges and credits are the same and they are therefore always balanced. The material accounts are first corrected by introducing the exact value of a carefully made inventory. This gives us the real cost for the material which has been actually used during the year. The next step is to adjust the production credit for the twelve months to the final charge. The difference between the two sides of the ledger is the amount of the adjustment and may be either plus or minus. The net result of all of these factor adjustments is carried to Expense Reserve and will either increase it or decrease it, as the case may be.

35 Bad accounts, depreciation charges, discounts, premiums, special expenses or any other accounts which need to be absorbed, are all transferred to Expense Reserve and the net balance of the

account is carried to Foundry Sales either increasing or decreasing the Factor Gain and this balance then becomes the real Sales Gain for the year.

36 The question of the cost of an individual job will not be discussed in this paper, neither will the method of estimating the cost of a lot of castings on which a bid is to be made. They are both handled in the same general way, the three facts core labor, molding labor and weight of castings being considered, with such changes in the factors as may seem necessary to meet the conditions.

37 In conclusion, we would say that the system as outlined is giving good satisfaction, the results are fairly accurate, and the comparative monthly data thoroughly reliable as a signal system.

DISCUSSION

Benj. D. Fuller (written). The cost system presented by the author is in the right direction and probably satisfactory as an accounting guide for a foundry such as the one where it has been applied; but in my estimation it does not go deep enough to be thoroughly successful in accounting for the costs of a large concern. Too little attention is paid to the question of overhead distribution, which is a very important factor.

Overhead is in some cost systems carried entirely as a percentage on direct labor cost; in others as a percentage added to poundage or weight. A more equitable distribution is to divide, carrying a percentage on labor and another percentage on weight. Some castings require an excess of labor for a minimum of weight, in which case the labor overhead would be the larger in the accounting, and justly so. But imagine a casting of excessive weight and a minimum amount of labor, such as a large floor plate cast in open sand. Here the weight basis of overhead would, in accounting, rightly carry the bulk of load.

Cost systems giving individual casting costs are much more valuable than those where the output is handled in bulk or weight classifications.

In Par. 3 it is stated that the three most important items are core labor, molding labor, and pounds of castings produced. To these should be added cleaning labor, which varies widely in cost with the class of work.

Par. 5 says that in the general scheme used an account is charged with the amount of the purchases made during the month. Payroll charges in connection should not be forgotten.

In Par. 6 it is said that all expenses are charged to the Expense Account. There should be sub-accounts for the various classes of expense to care properly for these charges.

The items Core Work, Molding, and Metal and Melting which the author uses in his records, should each carry a share of building repairs, light, heat, depreciation, insurance, taxes, administration, etc.

ROBERT S. DENHAM[1] (written). Product of whatever kind, consists of materials and the time of formative processes. In this paper the material is Metal, and the formative processes are Core Making, Molding and Melting.

By analysis we find that the handling of materials or metal involves the expenses of transportation, handling labor, rent of stock yard or room, interest and insurance on investment in material, shrinkage, etc.

Analysis of the formative processes will show that each requires more or less of the following expenses: Rent, heat, building repairs; depreciation, interest, insurance and taxes on equipment; power, light, water, ice, compensation insurance, supplies; repairs to equipment, wages of workmen, etc.

Administration and selling expenses include salaries, advertising, office supplies, telephones, bad accounts and collection expenses, discounts, traveling expenses, commissions, etc.

Further, there must be consideration of the expenses of packing and delivering the product to the local consumer or freight house.

The author arbitrarily selects the process of core making and charges it with the expenses of wages and supplies, the latter being charged on the basis of 30 cents to each dollar of wages paid to coremakers. None of the other expenses is considered in connection with core making.

He then burdens the molding with all of the other expenses of the business, including all of the operating and administrative expenses required by the core making and melting except an unexplained charge of 30 cents per 100 lb. on the melting process. His basis for the charge of this mass of unrelated items is the wages of the molders.

For some reason, also unexplained, he selects the items of supplies from the mass and charges for these at the rate of 6 per cent, while what he calls "Expense" is charged at the rate of 75 per cent on the wages of molders. Since both have the same basis in his plan, the same result would be obtained by a single charge of 81 per cent.

[1] Consulting Cost Engineer, Cleveland, Ohio.

A practical degree of exactness is essential in a matter as vital as the cost of production, and the writer holds the following principles to be fundamental:

1 The cost of an item of production is the sum of the expenses involved in its production and distribution up to the moment at which cost is determined.
2 Every cost element (expense item) is definite in amount and purpose, and anticipates a beneficial equivalent in service or commodity.
3 In the distribution or charging of expenses consideration should be given to the benefit derived, so that the charges may be justly assessed where the benefit is conferred and in true proportion to the measure of benefit.

If each of the above-mentioned items of expense be now considered it will be found that not one of them bears a relation to wages such that the benefit conferred by the expenditure increases or decreases with fluctuation in wages, or as between the product of men receiving different rates of wages. Neither is there a relation between the wages paid and the total of these items which is applicable to the product of the workmen.

The correct determination of cost of product can be accomplished only through the comparatively new analytical method known as "cost engineering," in which each process is considered separately and each item of expense individually applied by measurement so that expense and benefit are in identical proportions, making it impossible for one process to carry any of the expense belonging to another.

Robert E. Newcomb (written). It is axiomatic that in the management of any business, facts, not surmises, must form the basis of operating.

While the costs of core materials, molding materials, expense and melting assumed in the paper may be functions respectively of the core labor, molding labor and pounds of castings produced, they are at the same time variable functions and hence, basically, surmises which cannot form an accurate basis for operating.

The object of cost accounting is to establish and fix profits, and a cost system should strive to get the absolute facts and figures. To arrive at proper cost the following well-established formulæ must be used:

Cost of Material + Direct Labor = Prime Cost
Prime Cost + Direct Factory Expense = Factory Cost
Factory Cost + General Expense = Cost to Make
Cost to Make + Selling Expense = Cost to Make and Sell

and in foundry cost accounting it is essential that the cost be built up from the following items representing the total of accumulated details: Core Labor, Supplies, Molding Labor, Chipping Labor, Miscellaneous Labor, Melting, New Metal, Scrap, Other Expense, each item in sum total.

The accumulated details should be obtained from the record of the actual number of units of material used from day to day and the actual number of hours of labor. The cost of material delivered during a current cost month should not be used as a basis of establishing costs, as is apparently suggested in Par. 14, as it would not give a true cost for the reason that the material entering the castings, especially in a foundry carrying a stock of iron, may have been delivered at a price differing considerably from the cost for the current month. This difference in price may make a considerable fluctuation in the selling price, which would apparently cause the foundry using this method to quote both low and high prices at the wrong time. A better method would be to average the cost of the pig iron and material in stock, thus preventing fluctuation in apparent cost and selling price.

As a signal to indicate the drift of the cost, a daily estimate may be made, based as follows, assuming a specific case for illustration:

Let M = total number of men = 175
T = total melt in tons = 35
P = average proportion of good castings in melt = 0.7
L = average cost of labor per day = \$4
I = average cost of metal at ladle per ton of good castings = \$25
S = average cost of supplies per ton of good castings = \$10
m = average number of men per ton of good castings $= M/(T \times P) = 175/(35 \times 0.7) = 7.10$
l = average labor cost per ton of good castings $= m \times L = 7.10 \times 4 =$ \$28.40
C = total cost per ton of good castings $= l + I + S$ = \$28.40 + \$25.00 + \$10.00 = \$63.40

The above figures are actual or based upon the previous month's accurately established costs, and from day to day are reasonable

signals indicating to the live foundryman the drift of the cost for the current month; and in the respect that they are available from day to day, corrective measures may be taken to reduce greatly increasing costs before they have run to a disastrous extent.

M. J. HOUSE[1] (written). It would seem that the author's plan fails to provide adequately for cost and accounting requirements under the ordinary conditions of a commercial foundry.

While not doubting in the least that, as stated, the system gives excellent satisfaction, that the data it keeps before the foundry officials are thoroughly reliable according to the plan and that the clerical work requires but little extra time, it does not follow that the costs are "fairly accurate." Numerous systems are in use which fully satisfy those who use them and, in many plants, statistical data of great importance are compiled, yet the costs obtained are far from dependable.

In Par. 3 the author sets up three independent variables, namely, Core Labor, Molding Labor and Pounds of Castings Produced, as the most important ones and considers all other items of cost as "functions" of some one of these.

As a general proposition, however, there are seven variables equally important, owing to their direct influence on costs although not in like proportions. These seven are Pattern Labor, Core Labor, Molding Labor, Melting Labor, Cleaning Department Labor, Materials and Supplies and Pounds of Castings Produced. Like a majority of founders, the author ignores the fact that labor employed in the pattern shop is directly related to production, is chargeable directly to jobs or classes and is not an item to be prorated over production as a whole if of consequence; there is no more reason for doing so than for the diffusion of Molding Labor in the same way.

The difficulty referred to in Par. 8 in respect to split payrolls is more imaginary than real; as, if accounting classification is properly devised and followed, the manufacturing accounts may be tied in with financial records without use of split payrolls and the twelve cycles for comparison annually may consist of two periods of four weeks and one of five weeks each three months.

I am not prepared to dispute the statement that the cost of melting varies directly with pounds of castings produced, but unless the quantities of the several patterns cast are identical each month, I

[1] With C. E. Knoeppel & Co., New York City.

am at a loss to understand how such a result can be achieved, as the cost of melting actually varies according to quantities of gates, sprues, defectives, over metal, etc. Unless the product is practically uniform from month to month, the melting credit cannot possibly parallel the production.

In a certain cost-accounting plan that has been found to be very simple, highly accurate and easy of application, melting and department expense rates are predetermined, all expense is concentrated into six rates, and when cost computations are made — which may be at any time a lot of castings is finished — the only factors to be dealt with to obtain Shop Cost are Metal and Castings, Direct Materials, Direct Labor, Departmental Rates and — sometimes — special costs in the form of patterns, flasks or other special rigging.

William L. Walker[1] (written). The method used by the author to distribute the Indirect Expenses may not produce large errors in the costs of the castings made in the particular foundry in question, provided the product consists of similar articles which are made according to similar standard operations, using similar furnaces and molds, and by employees working at about the same wages. However, in a large foundry which produces many kinds of castings, using different sizes and types of furnaces, molding machines and other equipment, or in a manufacturing plant where many different types of machines and equipment are used, and where the scale of wages represents many variations, the use of a factor, mentioned by the author, applied as a percentage on Direct Labor to distribute the Indirect Expenses might lead to many absurdities. For example, suppose a skilled mechanic who is paid 60 cents per hour is working at a bench where the rate per hour for bench space is 20 cents. The total cost for Labor and Indirect Expense in this case would be 80 cents per hour. Suppose also a machine operator who is paid 30 cents per hour is operating a machine where the rate per hour on the machine and space used is $1.50. The total cost of Labor and Indirect Expense in this case would be $1.80 per hour. If a percentage on Direct Labor were used, say, 200 per cent, the supposed cost for Labor and Indirect Expense in the first case would be 60 cents plus $1.20, or $1.80. The supposed cost for Labor and Indirect Expense in the second case would be 30 cents plus 60 cents, or 90 cents. The results

[1] Management Engineer, 6 Beacon St., Boston, Mass.

obtained by using the percentage-on-Direct-Labor method would show a charge of 90 cents per hour too much in the first case and 90 cents per hour too little in the second.

There are three classes of expenses in a manufacturing plant: Materials, Direct Labor, and Indirect Expenses. Each of these is distinct and does not necessarily bear any relation to the others. It is necessary to distribute the indirect, or overhead, expenses by departments representing various types of operations or divisible units in the manufacturing plant. Each department should bear its share of the expenses for space occupied, for machines and equipment used, and any other expenses chargeable to the department. A proper system of classification of expenses will place them in the accounting records in such a manner that they can be distributed to the various departments with minimum effort. Rates should then be determined for all machines and work places in the departments, subject to correction at any time when conditions justify, to be used for distributing the Indirect Expenses. By this method the indirect or overhead expenses are placed where they belong and are distributed in the costs on a time basis, independent of the other two classes of expenses, namely, Materials and Labor.

The greatest need in manufacturing plants is to develop proper methods, controlled by a proper organization, to reduce costs and allow for increased wages; but along with such a development it is absolutely necessary to have a good cost-accounting system as part of the plan, in order to show the results obtained and to provide a basis for selling prices. It would be absurd from a business basis to attempt to trace costs beyond the point where it requires a greater outlay to obtain the results than the actual differences involved in the method, but correct principles should be used in all cases.

R. Moldenke. After seeing the author's foundry in operation, one can understand the advantages of the system he describes in his paper. The work made in this foundry, while of quite a varied character — as it should be to be of educational value — is nevertheless continuous in its nature. The molds and cores are repeated again and again to an extent that make a system such as he has worked out very applicable, indeed. Whether this system can be used effectively for other lines of work, much less constant in daily production, is another question.

The "pilot light" idea is unquestionably a good one in any case, as we want to be warned in time if there is a tendency to go

from profit to loss. On the other hand, however, we must know individual costs of castings to a point of closeness that will not become burdensome in its details. There eventually comes a time when it is necessary to differentiate the classes of work produced at a general foundry so that the overhead may be distributed properly for each. It may cost much less to sell a big engine bed than a lot of miscellaneous work of small weight, and hence an equal tonnage distribution of overhead is not correct. The class of work that gives the least profit must be ferreted out and raised in price or else left to the other fellow.

The contribution of the author is very welcome in that it points out the way for a closer study of foundry costs. If there is anything needed badly in the foundry it is just this information. Whatever system may be found best to cover individual cases, the results must be accurate enough to prevent bids for castings coming in which — presumably based upon the foundryman's actual cost records — may vary from four to eight cents a pound for the same piece.

MALCOLM LIBBY. It is to be hoped that the author will present at an early date this question of prices and bids because it would make clear many of the points of the paper, and in the discussion especially so, inasmuch as the judgment which is made on the foundryman; i.e., the superintendent's efficiency and capability, involves several factors. He mentioned an all-important one, namely, the selling price turned immediately back to production. Some companies are in a fortunate position in that they are able to establish the market price. Their cost systems must involve the principle which covers the question of determining the price quite as much as determining the costs.

WILLIAM KENT. For the purposes of the particular foundry in question the author's system may give a close enough approximation to what he wants to get; but I agree with those who have preceded me in saying that the system will not do for any foundry operated on different kinds of products, and that some other system must be used. The objection to Professor Bird's method is that he uses factors and percentages. Generally speaking, averages and percentages and factors should be avoided. What we want is items summed up into totals and these totals put into proper reports, and if possible charted so that we can see how things are going. The idea of using an accounting system as a signal is good. The

best signal is found not in an accounting system, but in the reports of tonnages and other items that are put in a table of monthly averages.

THE AUTHOR. It is very evident from the discussion of this paper that exact foundry costs are considered very essential by some of our members. The object of this paper, however, was not to show how the cost of producing a given casting could be determined, but rather to point out a system of allowances for foundry costs by which an immediate line can be had on the monthly profits as well as check on the correctness of the factors used; all of this being accomplished in connection with the office accounting work.

In other words, the paper does not deal with cost keeping as such, and it therefore does not seem worth while to answer the various criticisms that have been offered from that viewpoint.

In closing, it might be well to say that the paper was presented to the Society in response to a request for a report on some of the research work being done at the Worcester Polytechnic Institute, and a careful reading will show that the system outlined is the result of several years of experimental work conducted along engineering lines in the Institute foundry. The factors and figures as given apply only to our foundry, but the general principles of what we have called the "signal system" can be applied to any foundry where the management really wants to have a monthly indication of how things are going.

No. 1640

THE PUBLIC INTEREST AS THE BED ROCK OF PROFESSIONAL PRACTICE

By Morris Llewellyn Cooke, Philadelphia, Pa.
Member of the Society

The object of this paper is to determine what has been, and apparently continues to be, the attitude of engineering organizations toward society as expressed in their rules of conduct. This, according to the author, is a time of stock taking and of a critical examination of the orders under which society and its constituent elements are operated. Within the church, among labor organizations, in government, in the educational field and in the professions, — everywhere, in fact, the same searching inquiry is going on as to aims and methods, and it is his belief that there can be no better time for a review of the codes of ethics designed to regulate the professional practice of engineers. It is further sought to develop the engineer's concept of his public relationship and responsibilities as contrasted with such relatively minor obligations as those to the profession of engineering, to a client, to fellow-engineers, and to himself.

THERE has been in our conduct since the beginning of the war, the clearest recognition on the part of this Society of the paramount obligation which we owe to the Nation, and, in the last analysis, to humanity. In view of this attitude taken spontaneously in time of war, it is curious to note that our public responsibilities are almost ignored in the codes of ethics of our organized associations of engineers. Drafted as they have been to control our conduct in times of peace, these canons of professional practice carry almost no reference to the public interest as a controlling, much less as a paramount, obligation of the individual engineer, of engineering societies, and of the profession as a whole.

2 This is a time of stock taking and of a critical examination of the orders under which society and its constituent elements are operated. Within the church, among labor organizations, in government, in the educational field and in the professions — everywhere, in fact, we find the same searching inquiry as to aims and methods. Hence, there can be no better time for a review of the codes of ethics

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designed to regulate the professional practice of engineers. The object of this paper is to determine what has been, and apparently continues to be, the attitude of engineering organizations toward society as expressed in our rules of conduct. It is further sought to develop the engineer's concept of his public relationships and responsibilities as contrasted with such relatively minor obligations as those to the profession of engineering, to a client, to fellow-engineers, and to himself.

3 The oldest, the largest, and perhaps the most representative society of American engineers, the American Society of Civil Engineers, for instance, makes absolutely no mention in its Code of Ethics of any such public responsibility. The Code in full is as follows:

It shall be considered unprofessional and inconsistent with honorable and dignified bearing for any member of the American Society of Civil Engineers:

To act for his clients in professional matters otherwise than as a faithful agent or trustee, or to accept any remuneration other than his stated charges for services rendered his clients.

To attempt to injure falsely or maliciously, directly or indirectly, the professional reputation, prospects, or business, of another Engineer. To attempt to supplant another Engineer after definite steps have been taken toward his employment. To compete with another Engineer for employment on the basis of professional charges, by reducing his usual charges and in this manner attempting to underbid after being informed of the charges named by another. To review the work of another Engineer for the same client, except with the knowledge or consent of such Engineer, or unless the connection of such Engineer with the work has been terminated.

To advertise in self-laudatory language, or in any other manner derogatory to the dignity of the Profession.

4 The first of these three sections refers exclusively to the engineer's relationship to the client, the second to his relationship to fellow-engineers, and the last simply deprecates advertising.

5 In the Code of Principles of Professional Conduct adopted by the Board of Directors of the American Institute of Electrical Engineers (but under the Constitution, never voted upon by the membership at large), there is a section devoted to The Engineer's Relations to the Public, which reads as follows:

The engineer should endeavor to assist the public to a fair and correct general understanding of engineering matters, to extend the general knowledge of engineering, and to discourage the appearance of untrue, unfair or exaggerated statements on engineering subjects in the press or elsewhere, especially if these statements may lead to, or are made for the purpose of, inducing the public to participate in unworthy enterprises.

Technical discussions and criticisms of engineering subjects should not be conducted in the public press, but before engineering societies, or in the technical press.

It is desirable that first publication concerning inventions or other engineering advances should not be made through the public press, but before engineering societies or through technical publications.

It is unprofessional to give an opinion on a subject without being fully informed as to all the facts relating thereto and as to the purposes for which the information is asked. The opinion should contain a full statement of the conditions under which it applies.

6 Even here, where public relationships are specifically mentioned, there is no recognition of the fundamental character of the obligation of the engineer to the public. Even the engineer's responsibility "to extend the general knowledge of engineering" is quite incidental. The major import of these injunctions has to do with a negative phase of the subject, i.e., the holding back from the public of inaccurate information or of too narrow statements with regard to engineering subjects.

7 The foregoing paragraphs are included, under the head of The Engineer's Relations to the Public, in the Code of our own Society, which was adopted in 1914. The following paragraph was added:

Engineers engaged in private practice should limit their advertising to professional cards and modest signs in conformity with the practice of other professions.

8 This Code of Ethics of the A.S.M.E. opens with two paragraphs on General Principles as follows:

It is not assumed that this code shall define in detail the duties and obligations of engineers under all possible circumstances. It is an axiom that engineers in all their professional relations should be governed by principles of honor, honesty, strict fidelity to trusts imposed upon them, and courteous behavior toward all. The following sections are framed to cover situations arising most frequently in engineers' work.

It is the duty of engineers to satisfy themselves to the best of their ability that the enterprises with which they become identified are of legitimate character. If an engineer after becoming associated with an enterprise finds it to be of questionable character, he should sever his connection with it as soon as practicable, avoiding in so doing reflections on his previous associates.

Then follows a section on the engineer's relations to client or employer, beginning with this statement:

The engineer should consider the protection of a client's or employer's interests *his first obligation* (Italics mine), and therefore should avoid every act contrary to this duty.

This sentence is fairly typical of what appears to be the keynote not only of this but of every engineering code. These codes have apparently been drawn principally and almost solely to hold up a high standard of personal integrity in relations with the client and to protect one engineer against another.

9 It is sometimes argued that to a consulting engineer are permitted higher standards of professional practice and conduct than to those who work for a single employer, and for a salary. But quite to the contrary, the code of the American Institute of Consulting Engineers places the greatest possible emphasis on the relation of the engineer to the client. In fact, there is no reference, direct or indirect, to the public interest. The code opens with these paragraphs:

It shall be considered unprofessional and inconsistent with honorable and dignified bearing for any member of the American Institute of Consulting Engineers:

(1) To act for his clients in professional matters otherwise than in a strictly fiduciary manner, or to accept any other remuneration than his direct charges for services rendered his clients, except as provided in Clause 4.

All that follows is simply a further elaboration of this general thesis. The preamble to the Constitution and By-Laws of this association, in common with all other engineering organizations, states that one of its objects is "to increase the usefulness of the profession to the public at large." But nowhere in the code is participation in this program made obligatory on the members.

10 The codes of The Institution of Civil Engineers and of the Association of Consulting Engineers of Great Britain similarly deal exclusively with the relations of their members to clients and to fellow-engineers.

11 Perhaps the most enlightened statement as to professional ethics which has thus far emanated from the engineering profession is the following, taken from the principles adopted by the Committee on Engineering and Coöperation, at its meeting at Chicago on March 29 and 30, 1917:

Ethics. Each local engineering society should adopt and frequently make application of a code of ethics prepared in accordance with the standards established by the national organizations or approved by other professional bodies. It is recognized that while it is impossible to prevent all violations of such a code yet eternal vigilance is the price of maintenance of high standards. The enforcement of such a code is essential to the well-being of the community at large as well as for the protection of professional men from the improper competition of unskilled or unscrupulous men tending to reduce the opportunity for effective service to individuals and to the public.

12 The omission of any reference to the public interest in the codes of professional practice of engineering organizations would not be so noticeable were it not for the fact that other associations of professional men have been at very considerable pains not only to express the obligation, but to insist on its paramount importance, and to phrase it in terms of lofty idealism.

13 The architects, whose work in many respects is quite comparable to that of the engineer, have been emphatic and successful in their efforts to govern their professional conduct along ethical lines. They have further made the effort to stress the public character of the profession, and to reward those who have made distinct contributions in the public service.

14 The American Institute of Architects, in its Circular of Advice Relative to Principles of Professional Practice, speaks as follows of the architect in this public relationship:

> He is engaged in a profession which carries with it grave responsibility to the public. . . . To his clients, to contractors, to his professional brethren, and to the public. . . . The fact that the architect's payment comes from the client does not invalidate his obligation to act with impartiality to both parties. . . . An architect should be mindful of the public welfare, and should participate in those movements for public betterment in which his special training and experience qualify him to act. He should not, even under his client's instructions, engage in or encourage any practices contrary to law or hostile to the public interest; for as he is not obliged to accept a given piece of work, he cannot, by urging that he has but followed his client's instructions, escape the condemnation attaching to his acts. An architect should support all public officials who have charge of building in the rightful performance of their legal duties.

15 The following quotations are taken from the Principles of Medical Ethics of the American Medical Association:

> A profession has for its prime object the service it can render to humanity; reward or financial gain should be a subordinate consideration. The practice of medicine is a profession. In choosing this profession an individual assumes an obligation to conduct himself in accord with its ideals.
>
> There are occasions . . . when a physician must determine whether or not his duty to society requires him to take definite action . . .
>
> A physician . . . should . . . always respond to any request for his assistance in an emergency or whenever temperate public opinion expects the service.
>
> The obligation assumed on entering the profession requires the physician to comport himself as a gentleman and demands that he use every honorable means to uphold the dignity and honor of his vocation, to exalt its standards and to extend its sphere of usefulness.
>
> Physicians, as good citizens and because their professional training specially qualifies them to render this service, should give advice concerning the public health of the community. They should bear their full part in enforcing its laws

and sustaining the institutions that advance the interests of humanity. They should coöperate especially with the proper authorities in the administration of sanitary laws and regulations. They should be ready to counsel the public on subjects relating to sanitary police, public hygiene and legal medicine.

Physicians, especially those engaged in public health work, should enlighten the public regarding quarantine regulations; on the location, arrangement and dietaries of hospitals, asylums, schools, prisons and similar institutions; and concerning measures for the prevention of epidemic and contagious diseases. When an epidemic prevails, a physician must continue his labors for the alleviation of suffering people, without regard to the risk to his own health or life or to financial return. At all times, it is the duty of the physician to notify the properly constituted public health authorities of every case of communicable disease under his care, in accordance with the laws, rules and regulations of the health authorities of the locality in which the patient is.

Physicians should warn the public against the devices practiced and the false pretensions made by charlatans, which may cause injury to health and loss of life (author's italics).

In conclusion it is said: These principles are primarily for the good of the public, and their enforcement should be conducted in such a manner as shall deserve and receive the endorsement of the community.

16 Perhaps the most conclusive statement in this matter is that which appears in the Code of the American Bar Association under the head, The Lawyer's Duty in Its Last Analysis:

No client, corporate or individual, however powerful, nor any cause, civil or political, however important, is entitled to receive, nor should any lawyer render, any service or advice involving disloyalty to the law whose ministers we are, or disrespect of the judicial office, which we are bound to uphold, or corruption of any person or persons exercising a public office or private trust, or deception or betrayal of the public. When rendering any such improper service or advice, the lawyer invites and merits stern and just condemnation. Correspondingly, he advances the honor of his profession and the best interests of his client when he renders service or gives advice tending to impress upon the client and his undertaking exact compliance with the strictest principles of moral law. He must also observe and advise his client to observe the statute law, though until a statute shall have been construed and interpreted by competent adjudication, he is free and is entitled to advise as to its validity, and as to what he conscientiously believes to be its just meaning and extent. But above all a lawyer will find his highest honor in a deserved reputation for fidelity to private trust and to public duty, as an honest man and as a patriotic and loyal citizen.

17 Recent developments in the medical profession — already distinguished by its high ethical standards — prove that codes of ethics and rules of professional practice are susceptible of very rapid alteration and improvement. In an illuminating article, Current Developments in Medical Ethics, by Dr. Richard C. Cabot, of Boston, and published in the *Harvard Theological Review* for July 1916, Dr. Cabot said:

A doctor of my acquaintance recently said in public what every doctor says in private — that there are too many surgical operations performed by men who have not the skill to make the operation of benefit to the patient, with the result that many necessary operations are *not* done because so many people have come to distrust all or nearly all surgeons. Soon after this he was officially reprimanded by his local medical society for unethical conduct. Such statements — though no one denies their truth — should not be made to lay audiences, the society said. They diminish the public's confidence in the medical profession. The incident illustrates the shade of truth in Bernard Shaw's remark that the medical profession (like every other profession) is a conspiracy against the public.

18 The real cause of this instance of professional discipline — which took place in 1915 — was that the offender demanded straightforward, truthful answers to these questions:

What was the matter with the patient?
What did the doctor do to him?
What was the result?
If the result was not good, what was the reason?
Was it the fault of the doctor, the patient, the disease, or the hospital organization or equipment?

19 In the less than three years which have intervened since this "trouble" in the Boston County Medical Society, the act complained of has become good professional practice. The Regents of the American College of Surgeons have recently issued a pamphlet describing a program for hospital standardization, in which they appropriate for the use of the profession this standard which was heretical three years ago, and carry it a step further in saying that —

If the facts establish evidence that a physician or surgeon is unsafe in judgment, unworthy in character, untrained, lax, lazy or careless, in all honor and decency that individual should either overcome his deficiencies or withdraw from practice.

20 Engineers need not be told that an axiom is undebatable. Surely no one will hold that the public interest is not fundamental to all professional ethics and practices. It is not even necessary to vote on the proposition. The simple enunciation of the statement makes it so obvious that further action is in a way unnecessary. On the other hand, one must necessarily question codes of ethics and canons of professional practice which have been drafted without the clearest possible recognition of the fact that such rules and regulations must be interpreted in the light of public interest.

21 In much of the vital engineering of the time the determinations are inextricably interwoven with questions of public policy. In fact, enlightened public engineering is in many directions the insistent

need of the hour. If the established engineering agencies fail to respond both efficiently and disinterestedly to this call for service, others will inevitably be created more in the spirit of our great time.

22 Practically all the questions affecting professional practice among engineers that have been raised during the last few years would have settled themselves had this one standard of the public interest been held to be fully operative while at the same time the interest of the profession as a whole, the relations of the engineer to his client and those of one engineer to another engineer, were being safeguarded as far as consistent with the public interest.

23 We frequently hear it said both by engineers and by laymen that this is the day of the engineer, or rather that the day is just dawning when society must become increasingly dependent upon engineering. Can this day really arrive so long as the rules and regulations for our professional conduct are so largely taken up with rather crude and in many cases debatable injunctions, which have more to do with what might be called "keeping the peace" than with our immeasurably more important task of providing such an enlightened leadership in the present as will make our dreams of the future come true?

24 My own feeling is that every code now in use by engineers in this country and abroad should be entirely rewritten on much broader lines and in a more inspiring key. It is useless to undertake such revision unless we have determined that we shall open every such code with the clearest possible enunciation of the principle that no considerations of professional or other special interest shall weigh for one moment against the interests of the nation and of humanity itself.

In presenting his paper at the meeting, the author referred to features typical of the codes of the various engineering societies.

In the A.S.M.E. code, he said, there had been introduced a section relative to the engineer's relations to the public which slightly, though not materially, modified and enlarged the scope of the codes as usually drafted. The significant statement in the code, however, was that the engineer should consider the protection of clients' or employers' interests his first obligation, and therefore avoid every act that could be considered as in any way contrary to this duty.

In contrast were the principles or professional practice of our professional brothers, the architects, which decreed that the architect

should not engage in, nor encourage, any practice contrary to law or hostile to the public interests, even under his client's instructions.

The medical profession had for its prime object the service it could render to humanity. In choosing this profession an individual assumed an obligation to conduct himself in accord with its ideals. In its code it was stated that:

> Physicians should warn the public against devices practiced and the false pretenses made by the charlatans, which may cause injury to health and loss of life.

The same idea was to be found in the lawyer's code, which ended as follows:

> Above all, a lawyer will find his highest honor in a deserved reputation for fidelity to private trust and to public duty as an honest man and as a patriotic and loyal citizen.

Unfortunately, the author said, his experience as an engineer and as a public official had given him the best of reasons for believing that this spirit was not representative of the engineering ethics of today.

Recently in reading the life of John Fiske[1] he had found the following significant quotation relative to the moral principles of the Civil War:

> President Lincoln, by the summer of 1862, had come to see that the war as it had been conducted by the Administration had no clearly defined moral issue back of it, and that he could no longer find justification in continuing such a terrible conflict as he was waging against the people of the Southern States on the sole issue of an interpretation of the Constitution. He saw the necessity, for the salvation of the Nation, of getting the issue squarely on its merits as a moral issue — a conflict between the idea of freedom and the idea of slavery, and then uniting the moral and political forces of the North in support of this policy.
>
> To this end he moved on his own initiative; and one of the finest chapters in all statesmanship is the history of his skill, his patience, his wisdom, his faith in rousing the dormant moral feeling of the North and focusing it in support of his Proclamation of Emancipation.

Similarly, he believed that the successful prosecution of the war would be largely a question of the people's ability to keep it where President Wilson had placed it, namely, on high moral ground. This was not the work of one man, but of all the people, and in all their relationships, whether of town life, church life, or professional life.

"In this hour of real national peril," the author concluded, "can we do less than write into our code that from this day forth it is unprofessional for an engineer to safeguard any private or special

[1] John Fiske, Life and Letters, by John Spencer Clark, vol. 1, p. 189.

interest at the sacrifice of public welfare? Do we seek power, influence, prestige, opportunities? These and more will come when we provide for our profession this moral leadership."

DISCUSSION

FRED J. MILLER wrote that in his opinion the actual attitude and practice of the members of the A.S.M.E. with regard to public service were far in advance of the Society's code. If American citizenship meant anything, it meant that no citizen could honorably take part in work that he knew to be against public interest, and that principle applied to engineers, as well as to doctors, lawyers and architects. Now, when so many were making sacrifices for the general good, not only of our own country but of the whole world, would seem to be the proper time to rewrite the code in the spirit of the times.

RICHARD A. FEISS, in a written discussion, said that today every calling involved special knowledge and special training and the men pursuing these callings in the field or in the workshop should view their work as professional work; for each calling had become a profession. The majority of these men, moreover, were dealing more or less concretely and specifically with the handling of organized human effort, and this involved social and other problems inherently of public interest. It was therefore necessary that a society of professional men such as the A.S.M.E. take the leadership in making its prime object the setting up of standards for the profession and the development of a membership whose object was first of all the best service in both quality and quantity to the public interest.

H. J. MACINTIRE wrote that standing between the capitalists and the workingmen, materially speaking, was the professional man, who, having maintained a position at neither of the extremes of society, would be called upon for leadership during the period of reconstruction. He could make his position enviable and assume this leadership deservedly only by such conduct as would command the esteem and confidence of the public and the respect of his fellow-practitioners.

The engineer, in common with every person of education and sensibility, should be guided by the spirit of the law instead of by a slavish adherence to the letter. And surely it was not too much to

ask that The American Society of Mechanical Engineers take the lead in demanding this broader ideal by so framing its code that every member of the Society would be under pressure as a member (as well as an individual) to consider the interest of the community to be his greatest responsibility.

ROBERT J. HEARNE submitted a written discussion in which he said that while the Society's code of ethics might need rewriting, there was nothing in it directly antagonistic to the consideration of the public welfare by an engineer. The code must be read as a whole.

Although one section stated that "the engineer should consider the protection of a client's or employer's interest his first obligation," yet the preceding section said he must "be governed by principles of honor and honesty and should satisfy himself . . . that the enterprise . . . is of legitimate character, and if it is of questionable character he should sever his connection with it as soon as practicable, *avoiding in so doing reflections on his previous associates.*" There were times for keeping silent, and times when one should speak out, and it surely was unethical to keep silent when one knew of wrongdoing or incompetence.

It would be well, in his opinion, to amend the section first referred to as follows:

> The engineer should consider the protection of a client's or employer's interests his first obligation, and, therefore, should avoid every act contrary to his duty, *provided, however, that his client's or employer's interest does not infringe the rights of the public or any individual.*

CHARLES M. HORTON wrote that, in amending the code it would be well not to talk of things having to do with the "unprofessional" and "inconsistent" and "undignified," for that sort of admonition was not needed. What was needed, though, and which should be embodied in the code, was forceful language having to do with the spirit embodied in the phrase of "live and let live" — the things which, after all, were necessary if life were to be worth the living, not physically but spiritually, and a living to all, for all. Let it be written what we should do, not what we should not do; the negative, through inference, would take care of itself — and woe unto him who disobeyed and was found guilty.

C. WELLINGTON KOINER, in a written discussion, said that in times of peace the best interests of the Government were not con-

sidered very seriously. The scandalous claims and set-ups for intangible values that had been made before railroad commissions and other regulating bodies went to show how far some lawyers and some engineers would go in opposition to the public interest and in violation of their code of ethics.

"All for the state and the state for all" meant that its interest was to be considered first and at all times conserved, in order that individuals might at all times receive the maximum benefits from its protection. He believed with the author that every code now in use by engineers should be entirely rewritten on much broader lines and in a more inspiring key.

THOMAS M. ROBERTS wrote that business methods of long usage were in practice among engineers and contractors, and the custom of driving a sharp bargain was too often passed as legitimate. Such methods might be expected between man and man as long as ethical standards were held cheaply or of little value. But it was well to consider their effect on our country and its Government during the war, as well as the reflex action on the influence of engineers in public life.

It seemed unfortunate that the Government in assembling war materials had been repeatedly handicapped by the covert efforts of certain engineer-contractors who had inserted in their specifications misleading phrases which to the Government officials seemed correct, yet later resulted in considerable trouble and loss to the project in development. These men in their specified bids for public service covered the letter of the law, but they violated the ethical features of honest professional practice. Instances were on record where the Government had been obliged to pay for the difference in cost between the apparatus it originally specified and the different thing offered in the contractor's bid, which proved inadequate.

Such practices might not strictly be classed as acts of "Aiding the Enemy," but they represented a species of unethical dealings which no society of engineers or engineer-contractors should countenance.

Engineers should emphasize this fundamental feature of our republic that a public interest is inseparably bound to the common welfare, and therefore every engineer and engineer-contractor in dealing with a public interest is bound by an ethical tie, which is paramount to the written law, and he should have a keen sense of justice toward the common weal.

THORNTON LEWIS, in a written discussion, said that his observation led him to believe that engineers as a class fulfilled their duty to the public just as faithfully as did the men of the other professions such as doctors, lawyers, etc. This was no reason, however, why engineers' codes should not express the fact that public interest is the first duty. In fact, there were many positive reasons why they should, among them being the inspiration and stimulation to unselfish action which the younger men of the profession would and should receive from them.

Since engineers were more and more becoming dominating factors in public-service corporations and the manufacturing industries, could not in reality a better condition of society in general be brought around by helping them to see more clearly the path of duty to the public, which, in the long run, would be to the best interests of their corporations and to their best selves?

The new code of ethics must embody the thought that he who serves humanity most serves himself best.

A. F. NAGLE wrote that the founders of the Society were not indifferent to the ethical, or moral, character of its membership, as was evidenced by the fact that they required a rigid search to be made by the Council into an applicant's experience and character, and if favorably acted upon, his name was to be submitted to a voting membership consisting, at present, of over 8000, where but two negative votes would exclude him (see C 17). If, perchance, a bad man should slip in, he could at any time be expelled by a two-thirds vote of the Council (see C 25), hence one had to be not only a good man to get in but he had to remain good to stay in!

Mr. Cooke's plea that the public interest, be it city, state, nation, or humanity at large, should have paramount service from us, prompted him to ask what was implied. If the engineer was the sort of man we rightly assumed him to be, he would deal faithfully with all his clients. What more could he do? Mr. Nagle further stated that he had been in the employ of cities, state and nation nearly one-half of his business life, and could unhesitatingly say that the personnel of the engineers he had met in the public service had compared very favorably with those outside.

OBERLIN SMITH said that while it was undoubtedly true that the engineering profession owed much to the public which had fostered and used its work, the statement regarding the duty of engineers to

the public suggested, per contra, the duties the public owed the engineers. In this progressive age, with its enormous increase in efficiency due almost altogether to engineering to engineering inventions, why were the halls of Congress peopled with lawyers, merchants and farmers, not to say professional politicians, with scarcely an engineer in the whole conclave? The engineers, with their brethren the architects and physicians, had not only collaborated in the building up of science and art, but of the good morals and the health and wealth of their communities, and they certainly should have a large share in the making of laws which would tend to greater production, with greater efficiency, of the tools with which our civilization was builded.

As most engineers did not have time to become practical politicians, they would have to depend upon their non-engineering friends to work gradually toward such a reform. This could only be done by the promotion of a proper enlightened sentiment among the mass of the people. As this increases, might we not hope for a higher morale and greater efficiency in our state and national legislatures by the embodiment therein of more and more clergymen, physicians, architects and engineers?

James Reed, Jr., wrote that, judging from his own educational experiences, there was at technical schools an almost complete lack of emphasis placed on the importance of realization by engineers of the public interest.

He firmly believed that the remedy was a thorough and constant teaching at engineering schools of the higher ethics of the profession, the *citizenship duty* of the engineer, just as at West Point and Annapolis the highest ideals of patriotism and loyalty were unceasingly held before the students. He therefore offered the suggestion that a constant effort be made to hold before the student the importance of this realization in the practice of his profession: that the public interest is not to be forgotten or put aside for the benefit of the corporate interest.

L. P. Alford said that the discussion clearly called for a reframing of the Society's code of ethics. Associated with that reframing, however, should be the restatement of another provision of the Society, namely, the statement of the aims and objects expressed in its Constitution. They were quite narrow and technical, yet the tendency for the last few years had been to make the Society indus-

trial rather than purely a society of mechanical engineering. The activities of the Society had been broadened beyond its statement of aims. The restatement of the code of ethics was to reframe for the members the ideal of the duties of the engineer. When the revised draft of the code of ethics was presented there should also be presented a consistent revised draft of the objects and aims of the Society.

The following resolution was introduced by Mr. Alford, and was carried by vote of the meeting:

Because of the interest aroused by the paper presented by Mr. Morris L. Cooke at the Worcester meeting, and because of the frequently expressed belief that the work and activities of The American Society of Mechanical Engineers have outgrown its statement of aims and objects, it is respectfully suggested to the Council of the Society that steps be taken to reformulate the objects and aims of the Society as presented in the Constitution, and to recast the Code of Ethics of the Society to bring these in keeping with the interests and activities of the Society as a whole.

Calvin W. Rice said that he had been making the spirit of the paper a religion in his administration of the office of Secretary of the Society, and that he welcomed the opportunity to express his faith in the ideals of the engineering profession.

Mr. Cooke had referred to the way in which President Lincoln aroused the dormant moral feeling of the North in the support of his proclamation of emancipation, and he desired to point out that from the very fact that this feeling *was* dormant, it already existed in the minds and hearts of the people and needed merely to be aroused.

Mr. Cooke had also told how President Wilson, with great ability, had sensed the ideals of the Nation in this time of world war. In the same way as before, these ideals were already existent and needed only to be phrased; and he claimed for the engineers of the country, as individuals and idealists in an ideal profession, that they had contributed their share to the state of opinion and to the ideals of the Nation in the war, such as the President had expressed.

As a concrete example of this he would instance the dedication of the magnificent new clubhouse of the Dayton Engineers' Club: to the dissemination of truth and to the creation of civic righteousness. This was a cheering example of the new spirit of the Nation, which showed that in one case at least the engineering profession was alive to the spirit of the times.

He had recently made a study[1] of the stated objects of some

[1] This study was published in The Journal, September 1918, pp. 753–754.

ninety of the largest and best-known professional societies, including professions other than engineering, both in the United States and abroad, and had found but one engineering society — and, strange to say, it was in Germany — that in its constitution approached what the A. S. M. E. aimed to do. As nearly as he could remember, the objects of the Verein deutscher Ingenieure were twofold: devotion to the engineering profession, and to the development of engineering *for the benefit of the Fatherland.* Here, however, the one thing was lacking that was lacking in the whole of Germany: There was no expression of the spirit — it was all for the state.

It was not sufficient that we have the objects of the Society and of the profession for the benefit alone of the United States of America. That would be far short of the goal. We should, as Dr. Hollis had urged, reconsecrate ourselves to our new ideals, as displayed in the dedication of the Dayton Engineers' Club.

R. Sanford Riley referred to the broadening conception of the engineering profession, and said that when he entered the profession he had not realized that engineers were as well qualified as others for general service to their country. It was easy for engineers to criticise the fact that Congress was filled with lawyers and others in different lines of business, but it was largely the fault of the engineers themselves. They were growing in numbers and growing in importance. To grow proportionately in power they must be interested in larger affairs than their own. Worcester was important as a city largely because it was a city of engineers. They continued to form so large a proportion of the community that from necessity they had become accustomed to doing things in a public way — and the city had not lost anything in consequence.

The Author, in closing, called attention to a remarkable document, A Study in Hospital Efficiency, comprising a case report of the first five years of a private hospital, by E. A. Codman, M.D., 15 Pinckney St., Boston, Mass. The report was remarkable because it analyzed with freedom and truthfulness every case treated and showed whether there were errors on the part of the surgeon through poor diagnosis or lack of technique; faults in nursing; faults on the part of the patient, etc. This he instanced as an advanced step in professional ideals. The report also constituted a strong condemnation of fee splitting, which so often leads to unnecessary surgery. The application to other professions was obvious.

No. 1641

EFFICIENCY OF GEAR DRIVES

AN ACCURATE METHOD OF TESTING

By C. M. Allen, Worcester, Mass.
Member of the Society

and

F. W. Roys, Worcester, Mass.
Non-Member

The usual method employed in determining the efficiency of a gear drive is one in which the power loss is obtained by measuring the input and output and subtracting the latter from the former. In good drives, however, the efficiency is high and the input and output are very nearly equal, and any error in their measurement will result in a large per cent error in their difference, or the power loss. It is therefore evident that a method by which the power loss may be directly measured will be much more accurate.

The authors describe such a method, developed recently in the Mechanical Engineering Laboratories of the Worcester Polytechnic Institute. In the apparatus used an electric motor is so suspended in a cradle that both its armature and field are free to turn. The armature shaft is connected directly to the pinion gear shaft and the driven shaft directly to an Alden absorption dynamometer. The reaction of the motor field is balanced by the action of the dynamometer through a simple lever the arms of which are accurately proportioned to the ratio of the gears.

Results of tests on bevel-gear and worm-gear drives are given in tables and charts, and from the form of the curves presented and the consistency of the data the authors conclude that the method described is apparently the best yet devised for testing gear drives of all types.

APPARATUS for determining the efficiency of gears and other drives has recently been developed and used for making tests in the Mechanical Engineering Laboratories of the Worcester Polytechnic Institute. The fundamental principle of the apparatus consists in the direct measurement of the loss of power in the gear drive instead of the usual method of determining the input and output and subtracting one from the other.

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

2 Since the efficiency of good geared drives is relatively high, the input and output are very nearly equal, and any small errors in the measurement of these relatively large quantities will make a very large per cent error in the difference, which is the power loss.

3 It is therefore evident that a method by which the loss may be measured directly and independently of the input and output would be very much more accurate.

THEORY OF APPARATUS USED IN THE TESTS

4 The theory of the apparatus which was used in the tests is as follows: An electric motor is so hung in a cradle that both its armature and field are free to turn. The armature shaft is connected directly to the pinion gear shaft and the driven shaft directly to an Alden absorption dynamometer. The reaction of the motor field is balanced by the action of the absorption dynamometer through a simple lever. The arms of the lever are accurately proportioned to the ratio of the gears.

5 The general idea of the apparatus is as follows: An electric induction motor is hung in a cradle on double roller bearings, and an arm attached to the motor casing makes a cradle dynamometer. The motor shaft is connected directly to the drive shaft and an Alden dynamometer is put on the driven shaft. These dynamometers are so arranged that the force exerted by the end of the arms is downward. The arms of the dynamometers are of equal length and at the end of each is a fixed knife edge. A lever with three knife edges mounted upon it has the two outer knife edges adjusted so that the distance between them is equal to the distance (horizontal) between the dynamometer knife edges. The third knife edge divides this distance into segments whose ratio to each other is the same as the gear ratio. These three knife edges lie in the same straight line. The lever is now placed directly over the line between the dynamometer knife edges, and is supported by the third knife edge which rests on platform scales. The end knife edges of the lever are connected to the dynamometers in such a way that the high-speed dynamometer is connected to the long arm of the lever. A counterweight and a rider weight are mounted upon the lever. See Fig. 1.

METHOD OF TESTING

6 The method of testing, so far as the operation of the lever system is concerned, is identical for all tests, and therefore the explanation of its action is made perfectly general.

7 The center of gravity of the Alden brake was very nearly in the horizontal plane, so that a slight movement of the arm did not measurably affect its balance. The cradle dynamometer was so loaded that its center of gravity was only a short distance below the shaft center, and a load of 2 lb. at the end of the arm was enough to entirely upset its equilibrium. The lever was then placed in position as described above and statically balanced by means of the counterweight shown in Fig. 1. A long pointer attached to the lever showed the position of the system relatively to the initial condition of balance.

8 When the rider weight W was in its initial position, the load P_3 (see Fig. 1) was noted as the initial reading of the platform scales.

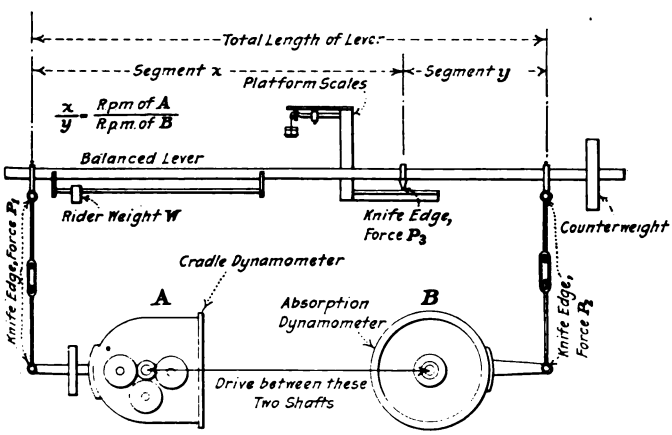

FIG. 1 GENERAL LAYOUT OF APPARATUS SHOWN IN FIG. 2

9 The variables entering into the balance of this apparatus are then the forces P_1, P_2 and P_3, and the displacement of the rider weight. P_3 may be measured at any time while the apparatus is in operation and so may the displacement of the rider weight.

10 It should be noted here that the amount of P_3 has nothing to do with the calculation of the power loss, which is found as follows:

METHOD OF MEASURING POWER LOSS

11 It will be seen from the preceding description and from Fig. 1 that $P_1x = P_2y$ for 100 per cent efficiency; but since the efficiency is never 100 per cent, P_1x must exceed P_2y by the amount necessary to overcome the loss in moment. This difference immediately upsets the balance of the lever, of course, but equilibrium may again be restored by shifting the position of the rider weight in the proper

direction. This displacement of the rider weight is therefore a measurement of the change of moment, and when corrected for the speed of the apparatus it is a measurement of the power loss.

12 Here the input power is automatically balanced against the output and any little change in the latter is immediately taken care of by the motor, and it is impossible for the apparatus to be out of balance except by the amount of the transmission loss. This is the feature of the method which distinguishes it from all others.

13 The power transmitted by the drive may be computed by

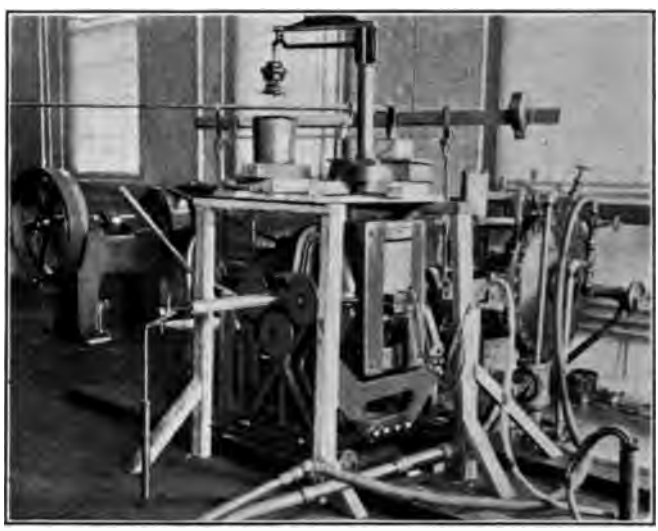

FIG 2—APPARATUS FOR TESTING THE EFFICIENCY OF BEVEL-GEAR DRIVES

noting the change in the load P_3 on the platform scales, and such computations will be shown later.

14 In operating it was found necessary to start the apparatus and let it run for several minutes before taking note of the initial position of the lever. The zero reading was frequently checked during the period of testing.

EFFICIENCY TEST OF BEVEL-GEAR DRIVE

15 *Data of Gears and Apparatus.* The gears were 5 per cent nickel steel, case-hardened, 5 pitch, 1½-in. face. They were cut by the Brown & Sharpe Mfg. Co. and were mounted by them on ball bearings especially designed for testing purposes. Fig. 2 shows the

apparatus set up for this test. Following are the preliminary data employed:

Number of teeth in gear	52
Number of teeth in pinion	14
Ratio, 52 ÷ 14	3.714
Total length of lever between outside knife edges (see Fig. 3)	3.95 ft.
Length of long arm of lever	3.112 ft. = 37.344 in.
Length of short arm of lever	0.838 ft. = 10.056 in.
Length of dynamometer arms	31.5 in.

A force of 2 lb. at 31.5 in. is equivalent to 1 hp. at 1000 r.p.m., for which the expression 1 hp_{1000} will be used.

16 *Calculation of Horsepower Loss from Movement of Rider.* Referring to Fig. 3, a force of 2 lb. at P_1 = 1 hp_{1000}. Therefore 2×37.344 = in-lb. of moment in lever necessary for 1 hp_{1000}, and if the rider weight is 3 lb., then for this to balance 1 hp_{1000}, $3x$ must equal

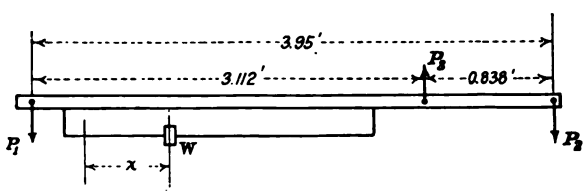

FIG. 3 DIMENSIONED SKETCH OF APPARATUS

2×37.344, whence $x = 24.893$, and therefore a movement of 24.893 in. of the rider is equivalent to 1 hp_{1000} for a 3-lb. rider.

17 If the rider weighs but $1\frac{1}{2}$ lb., then the same displacement means only $\frac{1}{2}$ hp_{1000}. A paper scale was made according to these figures and was fastened to the lever. The readings for hp. loss were taken from it throughout the test.

18 *Calculation for Horsepower Input.* Referring to Fig. 3, since the initial load of P_3 was taken with the rider weight W already on the lever, a change in the position of W does not change P_3, but merely changes the moment. Therefore, in moment equations of the lever, regardless of where the center of moments is taken, the arm of the moment of W is always the distance from the zero position.

19 The force P_1 is a measure of the input power if the speed is known, and it is merely necessary to calculate this value in order to solve the problem. Considering the moment equation of the lever, we have

$$0.838\,P_3 - 3.95\,P_1 + Wx = 0$$

whence

$$P_1 = \frac{0.838\,P_3 + Wx}{3.95}$$

If $W = 3$ lb.,

$$P_1 = 0.2122\,P_3 + 0.759\,x$$

if $W = 1.5$ lb.,

$$P_1 = 0.2122\,P_3 + 0.379\,x$$

x being the displacement of W measured in feet.

TABLE 1 DATA OF EFFICIENCY TEST OF BEVEL-GEAR DRIVE

PRACTICALLY NO LUBRICATION

R.p.m. of motor	Scale pan, lb.	P_3 lb.	$0.2122\,P_3$	x ft.	$0.759\,x$	P_1	Input, hp_{1000}	Input, actual hp.	Rider hp_{1000}	Hp. loss	Output, hp.	Eff'y, per cent
1	2	3	4	5	6	7	8	9	10	11	12	13
1115	5	200	42.44	1.70	1.291	43.731	21.86	24.37	0.746	0.832	23.532	96.6
1112	5	200	42.44	1.70	1.291	43.731	21.86	24.37	0.810	0.903	23.467	96.3
1112	5	200	42.44	1.70	1.291	43.731	21.86	24.37	0.770	0.859	23.511	96.5
1112	5	200	42.44	1.70	1.291	43.731	21.86	24.37	0.820	0.914	23.456	96.3
1119	5	200	42.44	1.70	1.291	43.731	21.86	24.37	0.806	0.899	23.471	96.4
1146	4	160	33.95	1.25	0.949	34.899	17.45	19.92	0.660	0.753	19.167	96.2
1146	4	160	33.95	1.25	0.949	34.899	17.45	19.92	0.615	0.702	19.218	96.5
1141	4	160	33.95	1.25	0.949	34.899	17.45	19.92	0.620	0.708	19.212	96.4
1141	4	160	33.95	1.25	0.949	34.899	17.45	19.92	0.612	0.699	19.224	96.5
1138	4	160	33.95	1.25	0.949	34.899	17.45	19.92	0.610	0.696	19.224	96.5
1160	3	120	25.46	1.00	0.759	26.219	13.11	15.14	0.486	0.561	14.579	96.3
1150	3	120	25.46	1.00	0.759	26.219	13.11	15.14	0.490	0.566	14.574	96.2
1150	3	120	25.46	1.00	0.759	26.219	13.11	15.14	0.486	0.561	14.579	96.3
1150	3	120	25.46	1.00	0.759	26.219	13.11	15.14	0.484	0.559	14.581	96.3
1172	2	80	16.97	0.62	0.471	17.441	8.72	10.25	0.316	0.371	9.889	96.4
1172	2	80	16.97	0.62	0.471	17.441	8.72	10.25	0.310	0.364	9.886	96.4
1177	2	80	16.97	0.62	0.471	17.441	8.72	10.25	0.308	0.367	9.888	96.4
1196	1	40	8.49	0.40	0.337	8.827	4.42	5.26	0.196	0.234	5.026	95.55
1196	1	40	8.49	0.40	0.337	8.827	4.42	5.26	0.204	0.243	5.017	95.35
1190	1	40	8.49	0.40	0.337	8.827	4.42	5.26	0.204	0.243	5.017	95.35
1205	½	20	4.245	0.37	0.281	4.526	2.26	2.72	0.184	0.222	2.498	91.9
1205	½	20	4.245	0.37	0.281	4.526	2.26	2.72	0.184	0.222	2.498	91.9

20 Referring to Table 1, for accuracy of recorded data the values in column 5 (x ft.) and column 10 (rider hp_{1000}) should vary together since they both refer to the displacement.

21 Column 10 is recorded for one purpose and read from the paper scale directly in hp_{1000}, while column 5 is recorded for another purpose and the measurement is recorded in feet measured by an ordinary rule.

22 It is necessary to read the values recorded in column 10 with as great accuracy as possible, but the approximate distance to the mean position as determined in column 10 is as close as it is necessary to record the values of column 5.

23 The values in column 10 after correction for speed give the total loss in power and become therefore the whole of the numerator of the equation for *loss* of efficiency, namely,

$$\text{Loss of efficiency} = \frac{\text{Hp. loss}}{\text{Hp. input}}$$

These values for hp. loss are recorded to three significant figures, but the third is somewhat in doubt, and therefore the absolute accuracy is only through two significant figures.

24 In figuring hp. input it is necessary to use the value P_1, which is obtained by means of the equation $P_1 = 0.2122\,P_3 + 0.759\,x$, where x is the value in column 5. The maximum variation in feet from the mean position (column 10) is less than 0.1 ft., but suppose that it was 0.1 ft.; then column 5 might have been 1.8 instead of 1.7 as in the first recorded line.

25 To see what the effect of such a discrepancy would be, the following computations have been made, taking $x = 1.8$ and $x = 1.7$, respectively:

$$\begin{aligned}
P_3 &= 200; \qquad 0.2122\,P_3 = 42.44 \\
P_1 &= 42.44 + 0.759\,x \\
&= 42.44 + (0.759 \times 1.8) \text{ or } = 42.44 + (0.759 \times 1.7) \\
&= 42.44 + 1.36 \text{ or } = 42.44 + 1.29 \\
&= 43.80 \text{ or } 43.75.
\end{aligned}$$

26 As hp_{1000} input $= \frac{1}{2}P_1$, then hp_{1000} equals either 21.90 or 21.865, and

$$\frac{\text{Hp. loss}}{\text{Hp. input}} = \frac{\text{Rider hp}_{1000}}{\text{Input hp}_{1000}}$$

whence

$$\text{Loss of efficiency} = \frac{0.746}{21.90} \quad \text{or} \quad \frac{0.746}{21.855}.$$

27 It is thus seen that, measuring as accurately as possible, the numerator is only accurate to the second place, the third being in doubt; and that the second place in the denominator is sure and the third fairly sure, although considered in doubt. Therefore the denominator is as accurate as the numerator.

28 The numerator is as accurate as the apparatus will allow data to be read, and therefore the inaccuracy of the data of column 5 has no effect on the final accuracy of the work.

29 In Test No. 1, the data of which are given in Table 1, practically no lubrication was used, the gears having been washed off

with gasoline. Previous to this there had been oil and graphite on the gears and some of the graphite still remained on the teeth. However, after running for a while they were practically non-lubricated. The 3-lb. rider had to be used in this case because of the amount of the friction loss, which, by the way, was sufficient to cause the gears to heat considerably.

30 Table 1 gives only a few of the results actually obtained, for the apparatus was started time after time and the balance by the rider gave the same results over and over again.

31 The next test was made to see how much the efficiency would be increased with good lubrication. Accordingly some heavy oil and flaked graphite were mixed and used as a lubricant. The

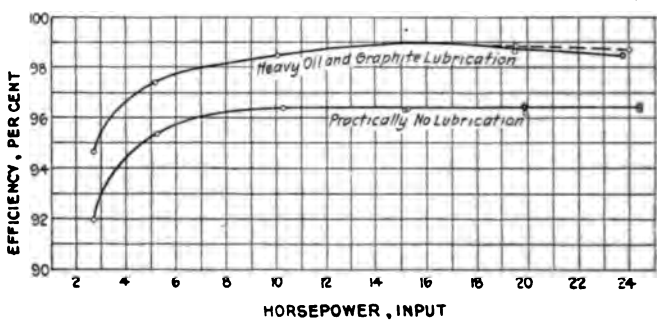

FIG. 4 HORSEPOWER-EFFICIENCY CURVES OF BEVEL-GEAR DRIVE
Gear ratio, 26 to 7; r.p.m. of pinion, about 1200

efficiency was so much increased that the 1½-lb. rider weight was sufficient, and again it was found that the same results were obtained time after time. The recorded data appear in Table 2.

32 Later, after the graphite and oil had become more perfectly blended, another test was made, the recorded data for which are given in Table 3.

33 The efficiency curves for these three tests are all given in Fig. 4. The difference between the results of non-lubricated and lubricated conditions is perfectly clear. The test with the more perfect blending of the lubricant showed results identical with the previous one except as indicated by the dash line at the end of the upper curve. This showed that the lubricant was not squeezed out from between the teeth at quite so low a pressure.

34 The form of the curves and the consistency of the readings convinced the experimenters that very reliable results had been obtained.

EFFICIENCY OF WORM-GEAR DRIVE

35 *Data of Gear, Worm and Apparatus.* The gear was made of phosphor bronze with 40 teeth; pitch diameter, 10.5704 in.; throat diameter, 10.9964 in.; circular pitch, 0.8302 in.; angle of teeth with

TABLE 2 DATA OF EFFICIENCY TEST OF BEVEL-GEAR DRIVE

HEAVY OIL AND GRAPHITE LUBRICATION

R.p.m. of motor	Scale pan, lb.	P_2 lb.	$0.2122 P_2$	x ft.	$0.379x$	P_1	Input, hp_{1000}	Input, actual hp.	Rider hp_{1000}	Hp. loss	Output, hp.	Eff'y, per cent
1109	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.330	0.365	23.355	98.4
1109	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.300	0.332	23.388	98.5
1109	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.302	0.334	23.386	98.5
1106	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.301	0.333	23.387	98.5
1106	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.303	0.335	23.385	98.5
1106	5	200	42.44	1.25	0.474	42.914	21.457	23.72	0.300	0.332	23.388	98.5
1139	4	160	33.95	0.90	0.341	34.291	17.145	19.49	0.228	0.259	19.231	98.6
1139	4	160	33.95	0.90	0.341	34.291	17.145	19.49	0.220	0.250	19.240	98.7
1135	4	160	33.95	0.90	0.341	34.291	17.145	19.49	0.225	0.256	19.233	98.6
1164	3	120	25.46	0.53	0.201	25.661	12.830	14.91	0.124	0.144	14.766	99.0
1164	3	120	25.46	0.53	0.201	25.661	12.830	14.91	0.124	0.144	14.766	99.0
1160	3	120	25.46	0.53	0.201	25.661	12.830	14.91	0.123	0.143	14.767	99.0
1175	2	80	16.97	0.50	0.189	17.159	8.579	10.08	0.120	0.141	9.939	98.45
1175	2	80	16.97	0.50	0.189	17.159	8.579	10.08	0.120	0.141	9.939	98.45
1175	2	80	16.97	0.50	0.189	17.159	8.579	10.08	0.120	0.141	9.939	98.45
1194	1	40	8.49	0.50	0.189	8.679	4.339	5.19	0.120	0.143	5.057	97.4
1194	1	40	8.49	0.50	0.189	8.679	4.339	5.19	0.120	0.143	5.057	97.4
1194	1	40	8.49	0.50	0.189	8.679	4.339	5.19	0.120	0.143	5.057	97.4
1200	½	20	4.245	0.50	0.189	4.434	2.217	2.67	0.120	0.144	2.526	94.6
1200	½	20	4.245	0.50	0.189	4.434	2.217	2.67	0.120	0.144	2.526	94.6
1200	½	20	4.245	0.50	0.189	4.434	2.217	2.67	0.120	0.144	2.526	94.6

TABLE 3 DATA OF EFFICIENCY TEST OF BEVEL-GEAR DRIVE

HEAVY OIL AND GRAPHITE LUBRICATION. GRAPHITE AND OIL BLENDED BETTER THAN IN TEST OF TABLE 2

R.p.m. of motor	Scale pan, lb.	P_2 lb.	$0.2122 P_2$	x ft.	$0.379x$	P_1	Input, hp_{1000}	Input, actual hp.	Rider hp_{1000}	Hp. loss	Output, hp.	Eff'y, per cent
1122	5	200	42.44	1.16	0.417	42.857	21.428	24.09	0.27	0.303	23.787	98.7
1124	5	200	42.44	1.16	0.417	42.857	21.428	24.09	0.27	0.303	23.787	98.7
1143	4	160	33.95	0.80	0.303	34.253	17.126	19.58	0.19	0.217	19.363	98.8
1141	4	160	33.95	0.80	0.303	34.253	17.126	19.58	0.185	0.212	19.368	98.8
1162	3	120	25.46	0.58	0.220	25.680	12.840	14.91	0.14	0.163	14.747	99.0
1177	2	80	16.97	0.50	0.189	12.159	8.579	10.08	0.12	0.141	9.939	98.4
1195	1	40	8.49	0.50	0.189	8.679	4.339	5.19	0.12	0.143	5.057	97.4
1200	½	20	4.246	0.50	0.189	4.434	2.217	2.67	0.12	0.144	2.526	94.6

axis, 38° 16′ 5″; normal circular pitch, 0.6518 in.; thickness of tooth, 0.3568 in.

36 The worm was made of Aurora steel, case-hardened, and had teeth; pitch diameter, 3.015 in.; outside diameter, 3.441 in.; cir-

cular pitch, 1.0524 in.; angle of teeth with axis, 51° 43′ 55″; thickness of tooth, 0.295 in.; lead, 7.4719 in.

37 This drive was made by the Brown & Sharpe Mfg. Co., and mounted by them in a ball-bearing case especially designed for the purpose of testing. The set-up of the apparatus was the same as for the bevel-gear tests (see Fig. 3), except that the positions of the knife edges on the lever were changed to agree with the new gear ratio, giving the following dimensions:

Number of teeth in gear	40
Number of teeth in worm	9
Ratio, 40 ÷ 9	4.444
Total length of lever between outside knife edges	3.645 ft.
Length of long arm of lever	2.9755 ft. = 35.72 in.
Length of short arm of lever	0.6695 ft. = 8.04 in.
Length of dynamometer arms	31.5 in.

TABLE 4 DATA OF EFFICIENCY TEST OF WORM-GEAR DRIVE

TEXAS CO'S. THURAN OIL LUBRICATION

R.p.m. of motor	Scale pan, lb.	P_2, lb.	$0.1837 P_2$	x, ft.	$1.647 x$	P_1	Input, hp_{1000}	Input, actual hp.	Rider hp_{1000}	Hp. loss	Output, hp.	Eff'y, per cent	Temp., deg. fahr.
1109	5	200	36.73	1.72	2.83	39.56	19.78	21.96	1.65	1.93	20.03	91.3	80
1109	5	200	36.73	1.88	3.09	39.82	19.91	22.10	1.90	2.11	19.99	90.5	150
1137	4	160	29.38	1.42	2.34	31.72	15.86	18.03	1.44	1.635	16.395	90.7	80
1137	4	160	29.38	1.48	2.44	31.82	15.91	18.10	1.50	1.706	16.394	90.6	150
1156	3	120	22.03	1.23	2.03	24.06	12.03	13.91	1.24	1.435	12.475	89.7	80
1156	3	120	22.03	1.10	1.81	23.84	11.92	13.75	1.10	1.270	12.480	90.8	150
1175	2	80	14.69	0.92	1.515	16.205	8.102	9.52	0.94	1.105	8.413	88.3	80
1175	2	80	14.69	0.82	1.35	16.04	8.02	9.42	0.82	0.964	8.456	89.9	150
1193	1	40	7.345	0.70	1.15	8.46	4.23	5.05	0.70	0.835	4.215	83.5	80
1193	1	40	7.345	0.53	0.872	8.217	4.11	4.90	0.54	0.645	4.255	86.8	150
1200	½	20	3.673	0.68	1.12	4.793	2.39	2.76	0.68	0.807	1.953	70.7	80
1200	½	20	3.673	0.45	0.740	4.413	2.20	2.65	0.46	0.554	2.096	79.1	150

38 *Calculation of Horsepower Loss from Movement of Rider.* The calculation for horsepower loss in this case is the same as for the bevel-gear test except for the change in length of the lever arm and the weight of the rider. In this test a 6-lb. rider was used and the equation is as follows:

$$6x = 2 \times 35.72$$

from which

$$x = 11.91$$

therefore a movement of 11.91 in. of the rider is equivalent to 1 hp_{1000} for a 6-lb. rider. A paper scale laid out according to these figures was used throughout this test.

39 *Calculation for Horsepower Input.* The equations are of the same form as those for the bevel-gear test and the figures are as follows:

$$0.6695\,P_3 - 3.645\,P_1 - Wx = 0$$

and for $W = 6$,

$$P_1 = 0.1837\,P_3 - 1.647\,x$$

x being the displacement of W measured in feet.

40 Considerable trouble was experienced at first in getting the initial balance of the apparatus as it was not at all sensitive. However, it was soon found that the weight of the Alden dynamometer caused a deflection of the shaft and consequently friction on the oil-retaining ring of the gear case, which had a very small clearance. When the weight of the dynamometer was taken from the shaft by means of a cord passed around the hub and an equalizing bar above,

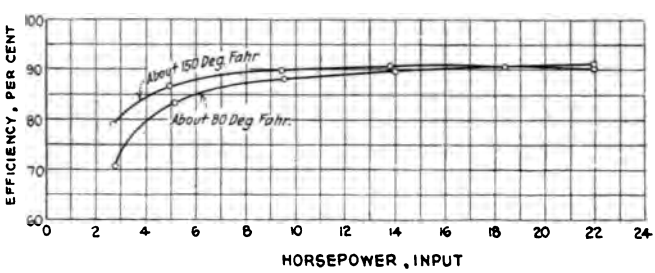

FIG. 5 HORSEPOWER-EFFICIENCY CURVES OF WORM-GEAR DRIVE
Results at two different temperatures of lubricating bath. Ratio, 40 to 9; r.p.m. of worm, about 1200

to which the ends of the cord were attached, the apparatus became sensitive at once. The purpose of the equalizing bar was to lift the weight without introducing any moment for slight movements of the dynamometer casing.

41 This apparatus ran without anywhere near as much vibration as the bevel-gear apparatus and it was accordingly easier to handle.

42 A heavy oil sold by the Texas Company under the name of Thuban oil was used for lubrication. The power loss in these gears was so large, however, that the temperature of the oil bath increased very rapidly. No tests were run to determine the limit of this rise or rate of increase, but tests were made at certain selected temperatures. Data of these tests are given in Table 4.

43 By testing at constant temperature the effect of the change in viscosity of the oil on the action of the lever was eliminated, but the effect on the efficiency is clearly shown by the curves in Fig. 5.

44 It is of course obvious that no test could actually be made at constant temperature, and the tests were really made by keeping the load constant and noting the loss as the temperature went up. These readings were recorded, however, as if the tests had been constant-temperature tests.

45 It is interesting to note in Fig. 5 that at the lower temperature, when the oil was viscous, the efficiency at light load was quite low, while at the higher temperature the efficiency increased, as one would expect, on account of its taking less power to churn up the thinner oil. But at the other end of the curves, that is, the high-power end, the reverse condition is found, indicating the inability of the oil to maintain proper lubrication at high tooth pressures when it becomes thin.

46 Again the form of the curves and the consistency of the data obtained point to the reliability of the apparatus.

47 It is accordingly concluded that this apparatus will measure accurately the efficiency of any positive shaft drive where both shafts are rotating at constant speed, and that it seems to be the best method yet devised for testing gear drives for efficiency, since it measures directly the actual power loss.

48 While this paper has described only tests of bevel- and worm-gear drives, tests of other drives have been made, and the method is applicable to all types.

DISCUSSION

Wilfred Lewis (written). I cannot quite agree with the authors' conclusion in Par. 47, but as a universal method, applicable to all types of gear drives, as stated in Par. 48, I think that they have developed a very simple and effective way of testing for efficiency and are to be congratulated on the novelty of the scheme.

In Par. 40 it is stated that some trouble was experienced at first and some interfering variables found, and this admission leads me to question the accuracy of the tabulated results. I do not see, for example, why the efficiencies under heavy loads should be so much higher than they were under light loads, unless the weight of the apparatus itself caused a good deal of loss in journal friction.

I have always found experiments on friction elusive and difficult to repeat with precision, and brake resistance particularly difficult to stabilize. For this reason, and also because I wanted to make endurance tests and study the effect of wear, the apparatus shown and described in Vol. 32 of TRANSACTIONS (1910) was designed and built. This had its faults, which led to a later design, described in June 1914, and still further improvements were made, as described in the *American Machinist* for September 28, 1916, and the October *Machinery* of that year.

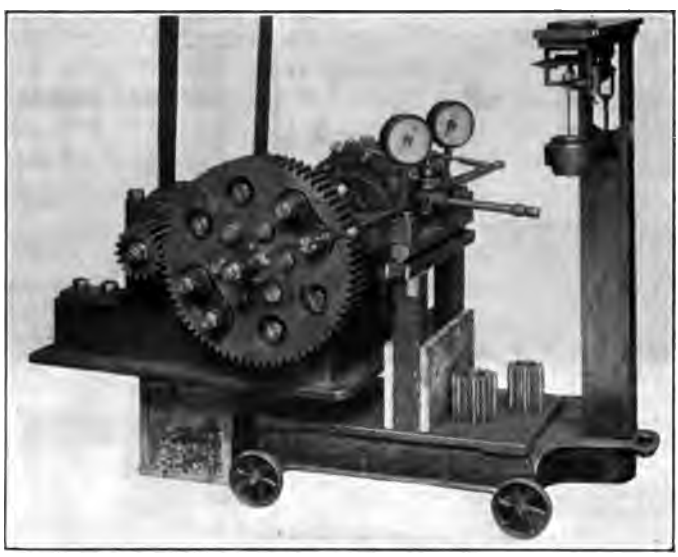

FIG. 6 LEWIS GEAR-TESTING MACHINE

The machine built for the University of Illinois is shown in Figs. 6 and 7, and is intended to measure the friction loss in the gear teeth when running at any desired pressure and speed.

Like the authors, I found that the friction loss in the teeth was sometimes 2 per cent or less, and also that in certain cases there was a somewhat higher percentage of loss under light loads, but it took so much longer to build the machine than was anticipated that very little time was left for experimenting.

I do not at all believe that the coefficient of friction between the teeth decreases as the pressure increases and am confident that the machine will demonstrate this, for the journal pressures are com-

paratively light because it uses only about 2 per cent of the power that the authors require for the same tooth pressure and speed.

The important thing in the apparatus shown in Figs. 6 and 7 is the friction load between the teeth, and that is what should be measured accurately. Along with it, to be sure, it is necessary to measure air resistance and the friction in the ball bearings and pipe joints. But while running at a given speed, the load on the teeth can be instantly released, and what remains is the air resistance and the swivel-joint and ball friction. By reversing the direction of rotation the zero scale readings can then be determined with great

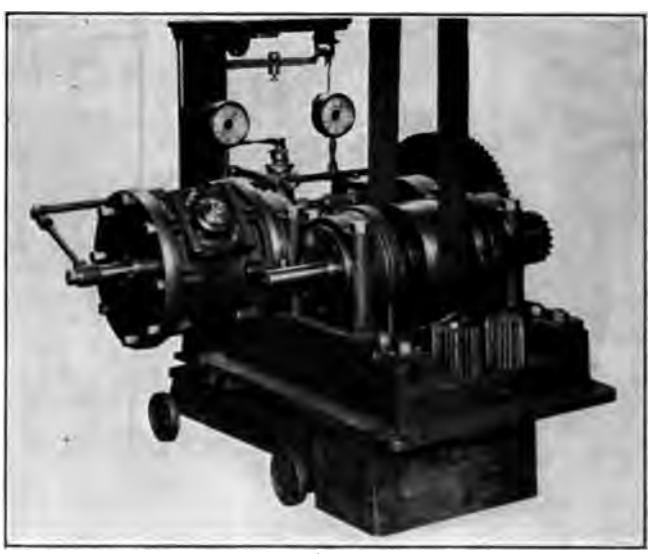

FIG. 7 ANOTHER VIEW OF GEAR-TESTING MACHINE SHOWN IN FIG. 6

accuracy, making it possible to show very positively just how much effect the friction in the teeth produced at any given pressure and speed.

The apparatus described in the paper would seem to be particularly well adapted to experiments upon the efficiency of worm gearing rather than for spur or bevel gears. Bevel gears are essentially the same as spurs, that is, in their friction analysis, but worms are different, and in worm gearing the friction loss is comparatively so great that the use of an absorbing power brake is really not exposed to the objection made when applied to the very minute losses in spur gearing.

The apparatus shown in Figs. 6 and 7 cannot be used in testing bevels or worms, but it can, I believe, test spur gears more accurately and thoroughly and furnish better data for a general analysis of the friction losses in spurs and bevels.

Many years ago I made numerous experiments on the transmission of power by gearing, which were reported in Vol. 7 of TRANSACTIONS (1885). Only cast-iron worms were used in these experiments, and I believe there is room for some good work now on combinations of steel and iron, steel and bronze and on hardened-steel worms running with cast-iron or bronze wheels.

I have not much faith in hardening, however, because a hardened pin always wears faster than the soft bearing in which it turns, and naturally enough the grit that works in sticks to the softer surface and grinds away the harder material. But the experiments should be made and I think the method devised by the authors could be used very successfully.

CHARLES T. MAIN said that when he first started in textile-mill work, bevel-gear drives were very generally used. No one knew exactly how much power was consumed in them, but it had been his practice to allow a loss of 5 per cent where the gears had been well designed and properly cut. Other engineers allowed as high as 10 per cent loss, but this, as the paper showed, was over three times too much.

WM. H. KENERSON said that those who had tried to obtain the efficiency of apparatus comprising bevel gears by measuring the power input and output mechanically, were aware of the difficulty experienced in getting accurate results. He had studied and experimented considerably along this line and knew of no apparatus that gave the results as simply as that described in the paper.

As to the efficiency of gears, he was inclined to think that it was more a function of the lubricant used than of the gears themselves, assuming properly cut gears; and it was to be hoped that the authors would answer some of the numerous questions engineers were asking about gears in general and the lubrication of gears in particular by conducting further experiments with their apparatus.

C. M. ALLEN. I would like to add that it makes no difference what gear ratio is used. If it is 1 : 1, then the lever is so divided that the fulcrum is at its center; if 1 : 4, the fulcrum is placed so

that the parts on each side of it are in the same ratio, and so on; the lever itself is the important thing.

In reply to Mr. H. G. Reist, I would say that while the power can undoubtedly be accurately determined by measuring the input in the motor instead of weighing the beam on the brake, I prefer the weighing method, as the result is visible.

Mr. Lewis questions the accuracy of results on account of the admission in Par. 40. If he will look at the paper, he will find that this trouble was only with the worm gear and did not exist with the bevel-gear apparatus, and that after all it was only on account of the clearance of a casing being too small. Since this is the fact, the authors fail to see where the question can be.

Mr. Lewis says that he does not see why the efficiencies under heavy loads should be so much higher than at light loads. Is it possible that Mr. Lewis does not realize that the curves must in the beginning theoretically pass through the zero of efficiency at no power delivered? for it will certainly take some power to drive the gears themselves. This being the case, it should be evident that the maximum of efficiency is attained only at some power for which the gears work best, and that between the zero and this point there is a rise in efficiency along some curve.

If the apparatus is good for one type of drive it is good for others and is not limited to worm drives as Mr. Lewis suggests.

When once the apparatus is balanced with the measurements of the lever ratio carefully made, the only thing that we measure is power loss; and the fact that an *absorbing power brake* is used has practically nothing to do with the accuracy, for no calculations of this power are necessary to get the power loss.

Since this paper was written we have made a large number of tests of worm gears as well as spur gears, transmitting as high as 50 hp., with entirely new apparatus but of the same design. The results of these tests strengthen every claim made by the authors in the paper.

In closing, the authors wish to acknowledge that the title of the paper is somewhat misleading. A better title for the paper would probably have been: An Accurate Method of Testing the Efficiency of Gear Drives.

No. 1642

AIR PROPULSION

By Morgan Brooks, Urbana, Ill.
Member of the Society

This paper describes experiments with propellers proving that the accepted screw theory of air propulsion does not accord with the facts. Air is impelled by a propeller at a speed approaching twice the screw advance for small blade angles, hence the theory of reflection or batting action should replace the screw theory. Thrust is shown to be due in greater degree to velocity and less to blade disk area than is commonly supposed. A method of predicting the complete flying performance of a propeller from a single static test of an accurate model is indicated.

THE term airscrew, considered by many writers on aeronautics as descriptive of propeller action, is a misnomer. The theory of the marine propeller, which seems to be adequately presented by the screw principle, has been transferred to air propulsion without sufficient regard for the extreme difference in the two fluids as to elasticity. Imagine automobile tires filled with water. In view of the current theory that air is driven by a propeller with a velocity never exceeding the product of the propeller's pitch and its revolutions, it was a surprise to find that air may be driven backward at a velocity nearly twice as great as this product indicates. The fact was so revolutionary as to cause the greatest care in measurement before its acceptance. Recognition of this superspeed action of propellers explains many anomalies of air propulsion and will undoubtedly lead to more exact formulæ for thrust and power calculations.

2 The purpose of this paper is to give proofs of the facts stated, and to point out some of the applications of the superspeed theory as it relates to propellers and blowers.

3 Superspeed is not observed readily in connection with the standard type of two-bladed propeller, owing to the masking of the effect by the mingling of high-speed air with a much larger quantity of inert air lying between the propeller blades. The measurements

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

were made upon a special type of propeller having extremely short blades of great width, sweeping the entire 360 deg. of the disk area, in fact. It should perhaps be stated that with the acceptance of superspeed the definition of slip as "the backward velocity of the current from a propeller" must be abandoned; but another definition of slip, "the shortage of velocity of translation as percentage of propeller screw advance," may survive owing to its convenience.

4 A propeller of the wide-blade type described having an experimental mean pitch of 2.53 ft., gives a wind on static test that flows 3.33 ft. per revolution, regardless of the rotation speed of the propeller. These values were determined for the writer by Prof. E. P. Lesley at the Leland Stanford Junior University wind tunnel, confirming his own measurements. The superspeed ratio, 3.33/2.53,

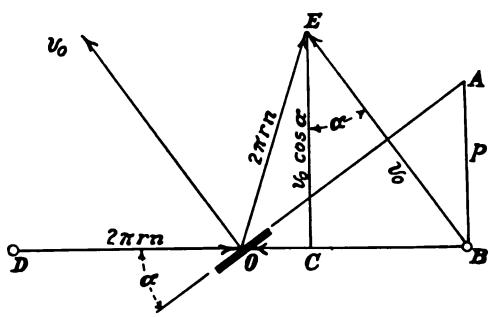

FIG. 1 DIAGRAM ILLUSTRATING TEST CONDITIONS FOR A WIDE-BLADE PROPELLER HAVING A BLADE ANGLE (α) OF 36 DEGREES

is 1.32, and these figures bear so direct a trigonometrical relation to the blade angle as to suggest that air instead of being swept backward by screw pressure is driven back by precise reflection or batting action.

5 The diagram, Fig. 1, illustrates nearly to scale the test conditions for the propeller mentioned above having a blade angle, α, of 36 deg. The blade element indicated at O is moving toward the left at the velocity indicated by the line $BO = 2\pi rn$, around an axis parallel to CE far below the plane of the paper, and strikes an air particle at point D. The relation of particle to blade is unchanged by assuming that the particle D moves to the right at same speed against a stationary blade, and is reflected to point E in unit time. Had the blade not been in the way the particle would have reached B, hence the blade has deflected the particle in the direction BE, represented also by the vector Ov_0 with respect to the plane. Ov_0

is perpendicular to the instantaneous position of the blade when striking the particle. Under the reflection theory assumed, the axial velocity of the air particle is the projection of this vector, that is, $CE = v_0 \cos \alpha = 2 \pi r n \sin 2 \alpha$. To the same scale BA represents pitch multiplied by revolutions, the accepted air velocity by the screw theory. Since $BA = 2 \pi r n \tan \alpha$, the ratio of superspeed velocity to screw-pitch velocity is $CE/BA = 2 \sin \alpha \cos \alpha / \tan \alpha = 2 \cos^2 \alpha$. For the 36-deg. angle of the special test propeller this ratio, since $\cos 36° = 0.81$, is 1.31, which agrees with the value 1.32 experimentally determined by pitot-tube measurement with sufficient precision to warrant acceptance of the reflection theory, especially when similar close agreement was found with a blade of 28 deg. angle and by other confirmatory tests.

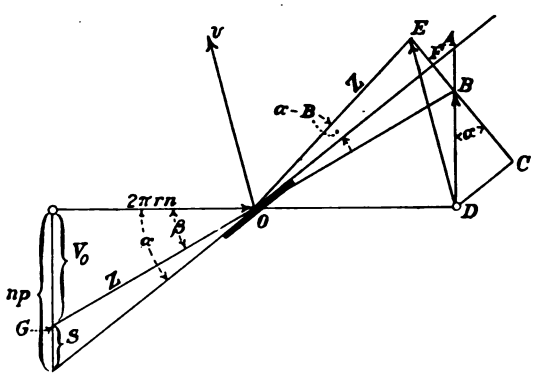

FIG. 2 DIAGRAM ILLUSTRATING TEST CONDITIONS FOR A PROPELLER OPERATING ON A FLYING PLANE OR IN A WIND TUNNEL

6 To illustrate the more complex condition of a propeller operating on a flying plane or in a wind tunnel with corresponding wind conditions, Fig. 2 is offered. Here, as before, the blade instead of rotating to the left at the velocity $2 \pi r n$, is assumed stationary, and the air particle at G is assumed to move to the right at the velocity $2 \pi r n$, combined with the velocity V_0, also reversed, representing the plane's translational velocity, or, in the case of a wind tunnel, that of the impressed wind. In unit time the particle moves along the diagonal path Z, strikes the blade at O, and is reflected to E. The angle of incidence and of reflection is $\alpha - \beta$. But for the blade the particle would have reached B in the same time, so that the blade action is represented by BE, while under the screw theory the motion

would be BA, the slip, which is more clearly indicated as S at the left of the diagram. The axial projection of BE is $BE \cos \alpha$, not represented in the diagram, and the ratio $BE \cos \alpha / BA = 2 \cos^2 \alpha$, the same ratio as found for static test conditions. This relation is derived as follows:

$$BE = 2\,FE = 2\,Z \sin(\alpha - \beta) = 2\,Z\,(\sin \alpha \cos \beta - \cos \alpha \sin \beta)$$

but

$$Z \cos \beta = 2\,\pi r n = np \cos \alpha / \sin \alpha$$

and

$$Z \sin \alpha = V_0$$

hence

$$BE = 2 \cos \alpha\,(np - V_0)$$

and

$$BE \cos \alpha = 2 \cos^2 \alpha\,(np - V_0)$$

7 Thus either for static or flying tests an air propeller produces a velocity or a change in velocity which has a superspeed ratio of $2 \cos^2 \alpha$ as compared with the screw-advance theory. This factor varies from nearly 2 for low pitch angles found near the blade tip to 1 for a 45-deg. angle, the steepest blade angle for effective work in propellers. For a propeller of constant pitch equal to diameter, a normal design, the superspeed ratio is 1.8 for the blade tip and 1.4 at half radius. Since the activity of propellers is confined mostly to the outer half of the blades, normal values for superspeed would lie usually between 1.5 and 1.6.

8 In wind-tunnel tests, where alone velocities of the air can be measured satisfactorily, the propeller activity BE is combined vectorially with the wind velocity V_0, making the vector DE, represented also by Ov, the velocity to be measured. The difference between this and $DA = np$ is not very marked except at rather heavy slip conditions. For low blade angles, however, where the superspeed ratio is more pronounced, careful speed measurements show that the air leaves the propeller at higher velocities near the blade tips than part way in, a condition inconsistent with the screw theory for standard-type constant-pitch propellers. Eiffel's "Recherches" presents an elaborate collection of data showing this condition to exist, for which no explanation is offered, but the reflection theory explains it.

9 When the direction of the air flow from a static propeller is investigated by means of light ribbons, they show that the air moves in a direction strictly perpendicular to the blade angle, the condition demanded by the reflection theory but not by screw action. More-

over these ribbons indicate that the stream contracts in diameter slightly as it leaves the propeller with its rotating whirl, whereas with the squeezing action of a screw it would be expected that the air would be expanding rather than contracting. Fig. 3 is an isometric drawing to show this rotating, contracting whirl.

10 The most convincing demonstration of the velocity of air leaving a propeller faster than the propeller screw advance is found in a test made with two propellers connected in tandem, illustrating a wind-tunnel test. Calling the forward propeller a blower, for distinction, assume that it provides a wind at 30 miles per hour, or 44 ft. per sec., and that the propeller is driven in this wind at a speed

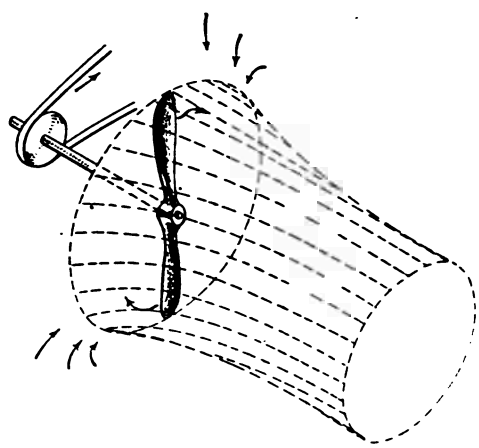

FIG. 3 SKETCH SHOWING DIRECTION OF AIR FLOW FROM A STATIC PROPELLER

just above idling speed, such that its revolutions times pitch is, say, 48 ft. per sec. An anemometer shows a velocity of about 50 ft. per sec. If now the blower be shut down, while the speed of the propeller is maintained constant, the wind velocity rises to 75 ft. per sec. instead of remaining constant as demanded by the screw theory.

11 Accepting superspeed, then, it is seen that since the air is driven backward at an excess rate, the thrust due to this unexpected acceleration is, by the Newtonian laws of dynamics, due in greater degree to speed and less to the quantity of air handled than is commonly supposed. It has long been recognized that the evaluation of dynamic thrust equations requires the questionable assumption

of blade activity over a larger portion of the propeller disk than that covered by the blades alone. Indeed some authorities, such as Riach,[1] use the entire disk area as that actuated by the propeller. Seventy-mile flight at 30 per cent slip is commonly supposed to mean that the air is driven backward at 30 miles per hour, while its actual speed is nearer 50 miles per hour. This means that the column of air with respect to the plane is not 100 miles but about 120 miles per hour in length. No wonder it is difficult to get satisfactory results from air-dynamics formulæ now in use, except from well-developed empirical formulæ.

12 The proper interpretation of superspeed bids fair to reconcile the thrust and power values as derived from the static tests with those of wind tunnels or of flight, whereas it seems to be the common opinion today that flying performance cannot be predicted from static tests. With the precise air-dynamics formulæ sure to come, a single static test of a propeller should furnish all necessary data for the production of complete flying-performance curves.

13 As a preliminary empirical approximation the following formula may prove useful: $T = T_0 - T_0'$, where T is flying thrust, T_0 the static thrust at propeller speed n, and T_0' the static thrust at propeller speed V/p, where V is plane velocity and p propeller pitch. That is, T_0' is taken statically at what is idling speed in the wind. Since all static-thrust values are proportional to the square of the rotations, a single static thrust at any speed enables both T_0 and T_0' to be derived. The physical meaning of this seems to be that the wind-tunnel blower relieves the propeller of that portion of T_0 represented by idling speed, even though the propeller, giving superspeed, sends air backward when tested statically at speed V/p, faster than velocity V. Under this formula the flying thrust at 30 per cent slip is found to be 51 per cent of the static thrust at speed n.

14 Correct air-dynamics formulæ will not produce the changes in propeller design that might be anticipated, since propeller engineering is nearly always based on experience. The propeller, or air bat, is extraordinarily efficient today. However, it is hoped that this paper may lead to a clearer conception of the underlying physical principles of air propulsion.

[1] Efficiency Variation in Airscrews, *Aviation*, April 1, 1918.

DISCUSSION

N. W. Akimoff (written). The theory proposed in the paper apparently contemplates an infinite space of 30 in. vacuum, in which floats one particle of air — how large is so far unknown. The propeller blade runs into it and, in turn, experiences a slight reaction, although the particle feels it much more than the blade itself. Splendid! but what becomes of the hydrodynamics of this delicate problem? All propeller theories based on the supposition that the air is a material aggregation of separate particles, are absolutely worthless: the screws built according to such theories are as likely to give 84 per cent as 48 per cent, because the very foundation is shaky.

The least unsatisfactory theory of propellers is that which takes into consideration the vortex theory of sustentation. Lanchester claims priority in the idea, although many other scientists of not quite so great repute also claim to have discovered it first. (See A Review of Hydrodynamical Theory, etc., by J. S. Hunsaker, International Engineering Congress, San Francisco, September 1915.)

He who looks into the vortex theory of sustentation will at once abandon theories about air particles as related to pitch or slip. Here the lift is made dependent upon a certain section constant, called "circulation", and is equal to density times circulation times velocity *ad infinitum*.

The propeller blade can also be considered as a set of regular wing sections, for which the circulation is either known or can be calculated. This has been done with satisfactory results.

Fig. 3 of the paper looks unusual and it has very likely been drawn by inference and not as a result of calculations.

The subject of static tests as a basis for judging what the dynamic pull will be, is one of extreme difficulty, and here again the vortex theory is the only hope.

For the estimation of what the static pull will be within, say, 15 per cent or so, the writer has recently proposed the following crude formula: Static pull in lb. $= n^2D^4/2750$. (*Aviation*, 1917.) This appears to serve the purpose, but only within the prescribed limits.

Charles W. Howell[1] (written). Recognition must be accorded the superspeed or acceleration theory so ably set forth in the paper, if it is desired to clear away the misconception existing as

[1] Vice-President, Aeronautical Society of America, New York, N. Y.

to the result of the application of power to a rotating element having angularly disposed surfaces to produce useful work in such a light and elastic medium as air, and if it is also desired to reduce the proposition to an exact status so that better working formulæ may be had.

Superspeed, as Professor Brooks states, is not readily observed in a static test of a two-blade propeller, but conversely may be directly observed in translational or flying tests of conventional airplanes, which have frequently been observed to fly a greater distance in unit time than the revolutions-times-pitch design of their propellers should fly them. Were this phenomenon confined to airplanes flying *with* the wind, we might assume, with reason, that it was merely the product of revolutions and pitch minus slip, plus the velocity of the wind, but as the phenomenon may be observed to occur in substantially inert air and to a lesser degree in flying *against* moderate wind, it can only be explained in terms of velocity and impact — i.e., superspeed.

The air structure shown in Fig. 3 is quite characteristic of those produced under static tests by propellers of screw-pitch design. It has been observed, however, to vary radically under flying conditions, a beautifully clear example being shown by a screw-pitch propeller driven by a Gnome motor. This is a rotating-cylinder motor lubricated by castor oil, which frequently causes black smoke to be emitted from the exhaust ports. This smoke does not take the form of a rotating, contracting swirl, but forms into two ribbons or pennants which do not rotate but appear to change position with variation of motor speed.

It has also been noted that propellers differing from the conventional screw-pitch design will set up various forms of air structures. One has been observed to create a column substantially parallel and with small tendency to rotate. This would appear to approach the ideal condition, as it indicates a reduction of interference losses; that is, maximum acceleration or superspeed has occurred.

Experimental research with small model propellers appears to indicate that the air structure formed is influenced largely by the design of the rear or leaving edge of the propeller blade and may have a strong bearing on its efficiency, because the smaller the interference with or the mixing of the superspeeded air particles, the more nearly parallel will be the lines of force and the greater the efficiency.

May I venture to suggest the term "acceleration" as more indic-

ative of the physical result, and to express the opinion that the problem can be reduced to a precise condition and understanding by throwing out all considerations of screw and pitch and considering velocities and impact only?

G. De Bothezat (written).[1] The following may serve as a basis for a discussion of the flow of a fluid along a section of a propeller blade. Let it be assumed that we know exactly the direction along which the flowing fluid reaches a section of the blade (this

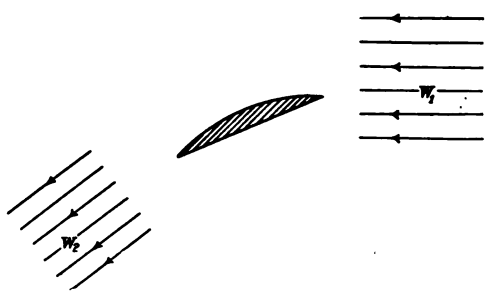

Fig. 4

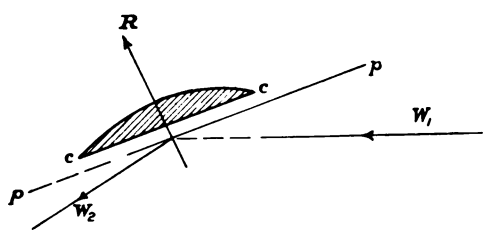

Fig. 5

theory determines exactly this direction). The following phenomena have then to be considered: If the flow reaches the blade section with a velocity W_1, it leaves it with a velocity W_2 (Fig. 4) which differs from W_1 in magnitude (slightly) and in direction. At the points of contact of the fluid with the blade section several quite complex phenomena of shocks and eddy formations manifest themselves. If the angle at which W_1 strikes the section of the blade is sufficiently small, then in the first approximation, and using the terminology adopted in the paper, W_1 is reflected on to the plane pp (Fig. 5) normal to the resultant of pressure R exerted by

[1] D.Sc., University of Paris. Scientific Expert, National Advisory Committee for Aeronautics, Washington, D. C.

the flowing fluid on the section of the blade under consideration. As a rule, this plane *pp* is not parallel to the chord *cc* of the section, but for small angles of attack (but not extremely small) the angle between *cc* and *pp* is not large. This applies only to small angles of incidence between W_1 and the section under consideration, and is correct only in the first approximation, though sufficiently correct for practical purposes.[1]

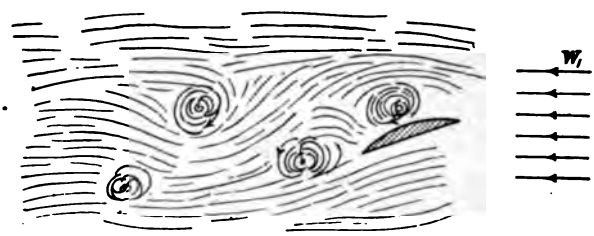

FIG. 6

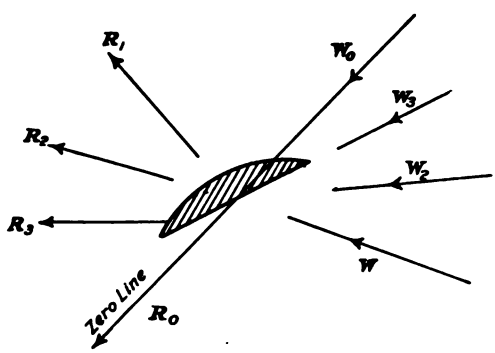

FIG. 7

I have arrived at this conclusion from a study of the phenomena of flow, and this is only an attempt to indicate more precisely the direction of the plane of reflection experimentally discovered by Professor Brooks. But there is more to it. As the incidence of W_1 with respect to the section increases, then, from a certain moment on, the flow of the fluid in the rear of the section ceases to be permanent, and eddies are formed to the rear of the section (Fig. 6). This fact is beyond all doubt and is confirmed by numerous experimental investigations, as, for example, those carried out at Ted-

[1] A detailed discussion of this question will be found in my paper entitled Introduction to the Study of Laws of Air Resistance of Aerofoils, published by the National Advisory Committee for Aeronautics.

dington. In such a case it is more difficult to speak of the direction of the reflected air current, and it becomes necessary to introduce the conception of a current equivalent to the complex system of flow. It can easily be seen how really complex is this problem, but the method which I use in my propeller theory enables me to take into account all the phases of the phenomena of flow without having to resort to any simplifying assumptions. Special attention has also to be paid to the following facts.

Let us consider a section of the blade which the air current strikes successively in the directions W_1, W_2, W_3 and W_0 (Fig. 7). The first resultants of the fluid pressure will be respectively R_1, R_2, R_3 and R_0, which means that as the incidence of W with respect to the section of the blade decreases, the resistance of R comes, so to speak, to lie in the section, and finally a moment arrives when

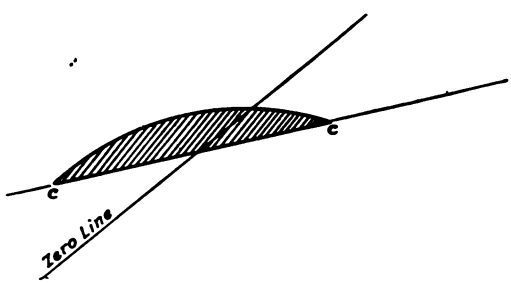

FIG. 8

W and R have the same direction. At that moment R has no component in a direction normal to W. I call "zero plane" (zero line on the section) the plane containing R_0 and W_0 when the component of R normal to W is zero. This zero line is located as indicated in the figure for nearly all sections of a propeller blade, and the angle which the zero line makes with chord *cc* (Fig. 8) depends on the profile of the section and may reach values in excess of 10 deg. For the majority of sections which I have examined this angle is comprised between 3 deg. and 12 deg.

When it is desired to compare a section of the blade to a thin ideal plane (geometric), it is of the utmost importance that the start should be made from zero line and that all the characteristics of the section should be referred to it. Thus, the incidence or angles of attack should be measured only from this zero plane. Likewise the pitch of the sections should be measured from zero line and not from the chord.

Nearly all of the misunderstandings concerning propellers are due to this fact. In Fig. 9, r is the distance from the axis of the propeller of the section under consideration; H is the pitch measured from the zero line, and W the velocity of the flow of fluid as it reaches the section under consideration. I call the pitch H when measured in the way indicated above the "effective pitch," as opposed to the geometric or constructive pitch measured from the chord. Only the effective pitch can be considered as the geometric and real characteristic of the propeller, and I fully agree with the author that the only possible definition for slip is

$$s = \frac{H - (V/N)}{H} = 1 - \frac{V}{NH}$$

where V = velocity of translation, N = number of revolutions, and H = effective pitch.

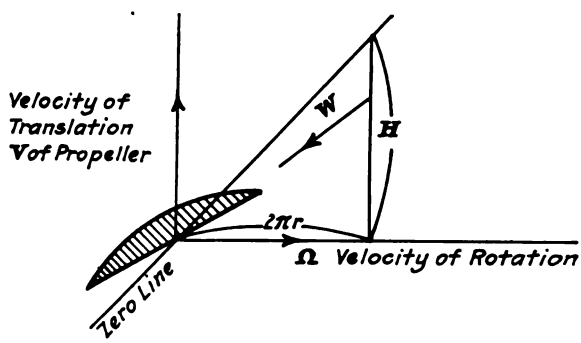

FIG. 9

It is the effective pitch which should be taken in measurements. It is always greater than the *constructive pitch*, and for this reason if for H in the above formula were taken the values of the constructive pitch, it might happen that negative values would be obtained for the propeller slip s, which is contrary to reason. The effective pitch, on the other hand, always gives positive values for s and the consideration of the effective pitch H is all that is necessary in order that the difficulties in the way of understanding the exact results of the experiments of Professor Brooks should disappear completely.

Let us consider the fluid stream generated by the rotation of a propeller; in particular, the case of a propeller rotating on a stationary base (the following reasoning is, however, perfectly general). I designate by S_2 (Fig. 10) the furthermost section to the rear of

the propeller and by $2\,v_0$ the velocity at one point of that section. $2\,v_0$ is the velocity of the fluid parallel to the axis of rotation at the given point and $2\,r''\omega_0$ is the tangential component of this velocity. The real movement of the fluid is obviously helicoidal.

I show elsewhere that the section S in which the velocities of the fluid are v_0^2 and $r\omega_0^2$, that is, exactly one-half of the velocities at the section S_2, must be located necessarily in the front part of the propeller and at a certain distance from it. The propeller is therefore necessarily comprised between the sections S and S_2. The section S_1 is that at which the eddy phenomena created by the propeller have already ceased to exist and the flow of air has become regular once more. The flow ahead of S is also regular, and my

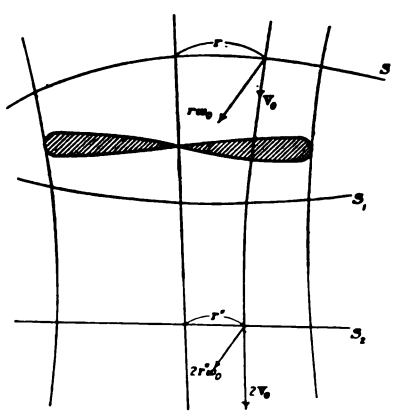

FIG. 10

theory gives the exact values of the velocities v_0 and $r\omega_0$ (or $2\,v_0$ and $2\,r''\omega_0$).

The following are the values above referred to:

$$v_0 = r\Omega_0\rho_0 \tan(\varphi + \beta_0)$$
$$\omega_0 = 2\,\Omega_0\rho_0 \tan^2(\varphi + \beta_0)$$

These formulæ will show, in the first place, in accordance with the experiments of Professor Brooks, that the ratios v_0/Ω_0 and ω_0/Ω_0 are independent of the number of revolutions $N = \dfrac{\Omega_0}{2\,\pi}$. In these formulæ

$$\rho_0 = \frac{\frac{1}{2}\,\Delta M\,(2\,v_0)^2}{\Omega_0 \Delta C_0} = \frac{v_0 \Delta Q_0}{\Omega_0 \Delta C_0}$$
$$= \frac{\tan(\varphi - i_0)}{\tan(\varphi + \beta_0)\,[1 + 2\tan(\varphi - i_0)\tan(\varphi + \beta_0)]}$$

and with i_0 secured from the ratio,

$$a = \frac{nb}{2\pi r} = \frac{2\sin^2(\varphi - i_0)}{k_i \cos(\varphi + \beta_0)}$$

These formulæ contain by implication the fact that the velocity at a certain point in the fluid depends only upon the characteristics of the section of the propeller blade swept over by the fluid stream passing at that point, which is true as long as the radial velocities are negligible.

In these formulæ ΔQ_0 and ΔC_0 are the thrust and partial couple which correspond to the section of the blade under consideration

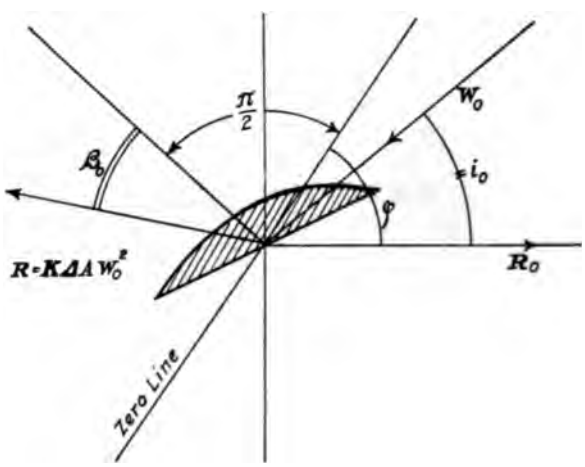

FIG. 11

and ΔM is the fluid mass which in a unit of time passes across the annular space swept over by the section under consideration.

k_i and β_0 are the aerodynamic characteristics of the section under consideration (Fig. 11)

φ = the angle of inclination of the zero line of the section under consideration on the plane of rotation

i_0 = angle of attack

n = the number of blades

b = the width of the blades

nb = the total width.

These formulæ for v_0 and ω_0 show again that the fluid stream generated by the rotation of a fixed-base propeller is geometrically similar to itself, independently of the velocity of rotation of the propeller, and that the angles of attack i_0 are independent of the

value of Ω_0. The values of the angles i_0 depend only on the shape of the blade and its pitch.

I have already by experiments confirmed the values of v_0 and ω_0 given by my theory.

Some propeller investigators have developed the following reasoning: If H is the pitch of a blade section, then the path traveled by that blade section in a unit of time when working as a solid screw will be NH. From this it is deduced that the air velocity behind a propeller working at a fixed point cannot be greater than NH. Now Professor Brooks has found experimentally that the air velocity behind propellers tested by him had a value very close to $2\,NH$. Thus with my notations $2\,v_0 \cong 2\,NH$, or $v_0 \cong NH$. If we now remember that v_0 is the velocity in front of the propeller we do not find anything astonishing in the experiments of Professor Brooks. Because when the angle of attack i_0 is small, v_0 has a value close to NH. Thus the experiments of Professor Brooks are perfectly correct and bring out clearly one of the most interesting properties of the flow around the propeller. The assumption that we must necessarily have $2\,v_0 < NH$ is simply a misunderstanding.

The physical reason for the increase of air speed behind the propeller is as follows: When the air crosses the propeller the action of the blades on the air is translated by an increase of pressure behind the propeller; now, as this pressure has to drop to the atmospheric pressure, the air velocity must increase; and this is why behind the propeller we always have the shrinking of the slip stream.[1] Only in the case of no shrinking of the slip stream could we ascertain that necessarily the air velocity behind the propeller ought to be smaller than NH. With regard to the air mass that passes in a unit of time through the plane swept by the propeller blades, it is evidently smaller than $\delta \frac{\pi D^2}{4} NH$, where δ is the air-mass density and D the propeller diameter, assuming a propeller with constant pitch. But as a result of the slip stream shrinking the velocity behind the propeller is increased and thus is generally greater than NH, and there is nothing paradoxical in this fact as above explained.

S. W. Stratton (written). The type of propeller employed by Professor Brooks in his experimental work differs so widely from the

[1] See footnote on page 126.

types in actual use that the extent to which the air-bat concept can be applied to propeller design cannot be foreseen. The new viewpoint is stimulating and suggestive, and especially welcome in connection with airplane propellers, where it is difficult to visualize what is actually taking place.

L. R. GULLEY (written). It was the writer's good fortune to observe a few of the tests made by the author, the results of which form the basis of this paper. On first examination, the most evident proof of the superspeed effect was the result obtained from the air helix or propeller arranged with short blades of such width that the entire circumference of the propeller was covered.

This arrangement prevents inert air from passing through the propeller, and would normally be an ideal condition for screw action as applied to hydraulic propellers. Anemometer tests, however, proved that the air was driven from the propeller in a reducing stream at a velocity in excess of the calculated amount derived from blade pitch and rotational speed, while the approaching air was drawn in radially toward the propeller.

The results clearly indicate the reflecting action of air, due no doubt to its volumetric elasticity, and it would seem that further research should develop data of value not only in the design of propellers, but also in improving wing action and possibly reducing head resistance of the stationary parts of the airplane.

J. C. HUNSAKER[1] (written). The author's statement in his introductory paragraph that "the accepted theory of air propulsion does not accord with the facts," is not substantiated in the paper.

The aerofoil theory as set forth by Lanchester and Drzewiecki, and now commonly used for the design of propellers, requires no assumption as to how an aerofoil element obtains its thrust, but bases the evaluation of this thrust on actual aerodynamic tests. The author makes an issue of the fact that calculated and actual propeller performances do not agree. This may well be accounted for by the necessary approximations made in design regarding indraft and a lack of definite knowledge of the action of the air at propeller tips and hub.

Professor Brooks' reflection theory, while it need not conflict with the aerofoil theory, is open to criticism. The assumption is

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made that particles of air act as independent bodies and not as parts of viscous fluid, and that they rebound from the propeller blade without interfering with the surrounding air. Photographic investigation of the flow of air around models does not show that any rebounding action affects materially the shape of the stream lines. Moreover, a rebounding action from the surface of an aerofoil is not in accordance with Dr. Prandtl's elaborate experiments demonstrating the existence of "bounding layers," nor does it harmonize with the "vortex theory of sustentation," which has been verified photographically.

In Par. 1 it is said that the theory of marine propulsion has been transferred to air propulsion without sufficient regard for the extreme difference in the two fluids as to elasticity. As previously stated, the design of a propeller is based on aerodynamic tests of the particular blade sections employed. Any effect that elasticity of air may have on air-propeller performance is accordingly taken care of in the choice of the proper blade section. There is extensive experimental proof that within certain limitations the same dynamic laws hold for water and for air. Perhaps the most striking example is afforded by a comparison of photographs of flow of air and water by models (Eden British Report No. 49). (In my paper given before the International Engineering Congress, 1915, I showed that the compressibility of air is mainly of theoretical interest.) A comparison of propeller tests made at the Navy Yard, Washington, with tests made by Dr. W. F. Durand, shows that there exists a close agreement between propellers tested in water and those tested in air and that it may be sufficient in particular cases to apply a correction only for the ratio of densities, as the compressibility of air is not a serious factor. The important effect of viscosity was not considered in the paper.

Regarding the conclusions drawn by Professor Brooks for static propeller tests, it may be said that no account was taken in his demonstration of "superspeed" for the acceleration of the air before coming in contact with the propeller blade. In consideration of tests made at the National Physical Laboratory and by Eiffel, his theory does not seem to warrant the neglect of "indraft."

A prediction of full-flight performance from a single static test as suggested does not take into account the critical changes which occur in the thrust of a propeller, as the angle of attack of the blade varies due to a change in the velocity of translation. It is not clear how a static test can foretell flying performance unless the aerodynamic properties of the particular blade are known.

M. B. SELLERS[1] (written). When a propeller is constructed having zero pitch, that is, the face or driving side exactly parallel to the plane of rotation, and having the usual cambered back, it is found that this propeller exerts some thrust and delivers a considerable blast of air. Of course there can be here no batting action, and yet we have a blast, due, in my opinion, to the fact that the rarefaction at the trailing edge on the back of the blade initiates an air stream. If now we try a similar propeller, but with an appreciable pitch, we find that the air stream produced is approximately the sum of that due to the cambered back plus that due to the pitch. On the other hand, if we employ a propeller having a blade flat back and front, the velocity of the air stream, correctly measured, will about equal the geometric-pitch speed. It would seem to me, therefore, that the increased velocity of the air stream observed is not due to batting action, but to the effect of the rounded back of the blade.

J. G. VINCENT[2] (written). I have submitted this paper to our propeller expert, F. W. Caldwell, and have asked him to give me a brief report, which he has done as follows:

"We have had some correspondence with Professor Brooks in regard to his theory of propeller design. He seems to be working under the impression that we wish to produce a noiseless propeller regardless of its efficiency.

"The first model propeller submitted by Professor Brooks to the National Advisory Committee of Aeronautics showed an efficiency of only 38 per cent in contrast with a model of Professor Olmstead's which showed an efficiency of 89½ per cent.

"Professor Brooks' paper is interesting from a theoretical standpoint, except that he seems to have drawn the wrong conclusion from his investigations. He seems to be under the impression that propellers with small diameters will produce good results, whereas all experience and all the usual propeller theories show that under most flying conditions the greater the diameter of the propeller, the better the efficiency obtained."

WALTER C. DURFEE (written). The most interesting explanation of superspeed as noted by Professor Brooks is in terms of the contraction of the jet or blast shown in Fig. 3. It seems certain that the velocity of flow actually among the propeller blades cannot be

[1] Member Naval Consulting Board of the United States, Baltimore, Md.

[2] Lieut-Col., U. S. A., Chief Engineer, Airplane Engineering Dept., Signal Corps.

great enough to drive the propeller any faster than it is being driven by the motor, unless the apparatus is acting as a windmill and the driving mechanism acting as a brake. The observed superspeed then is acquired immediately after passing the blades or may even exist to an extent at the blades, but in oblique directions. The contraction of the blast shown in Fig. 3 corresponds to a doubling of the forward speed of the propeller blast almost immediately after leaving the propeller.

An interesting explanation of this contraction and acceleration of the jet speed may be had without detriment to explanation in other terms by trying to study the action of the jet upon itself. The blast of a propeller of low pitch or of many blades is approximately a continuous jet or stream of variable cross-section. To describe it we may use the language of vortex motion. It is the same jet in any language. At its center this jet contains a complicated system of vortex motion corresponding to the internal rotation of the jet and the comparative lack of motion along the central axis.

The outside surface or sheath of the propeller blast is the seat of a second vortex system which is mainly responsible for the velocity of the blast and for the annulment of rotation and velocity in external regions. This outer system, which mainly determines the velocity of the jet, coils like a helix around the blast, with its origin at the propeller tips, much like the two serpents which coil about the "caduceus" or winged wand of Hermes, their two heads beneath the wings. Imagine these two serpents or snakes to grow interminably, continually fed from the propeller blades and their bodies rolling along as vortices between the jet and the outer air. Imagine, too, that every particle of moving air is the servant of these serpents and that the serpents themselves writhe with a motion exactly determined by the influence of all the neighboring coils. The result is a simple example in turbulent motion. The exact calculation of the motion of the serpents or vortices is not without importance if it can be accomplished. The thrust of the propeller, for example, depends on its angle of attack against the relative wind, and this relative wind is the abject slave of the serpents or vortices which feed on the propeller.

For the purpose of studying the reason for the contraction of the jet as mentioned by the author we may imagine that the jet is momentarily made straight and uniform like a pipe, i.e., uniform vortex coils from end to end. Under these conditions there is a collapsing motion at the entrance or beginning of the jet because the motion of the air here is due to the vortices immediately in front which roll

inward as viewed from the propeller. The velocity also in the supposed straight-walled blast may be studied. A forward component is provided by all the vortex coils. Within the tube the influence of these is felt both in the front and in the rear of any point, so the velocity is greater inside than at the entrance to the tube, where the influence is only in front. On the whole, the action of the jet upon itself is in favor of a contraction near the origin, and in favor of somewhat slower motion at the entrance than at a point a little within the jet.

If we could persuade a professional mathematician to "bell the cat" for us it would indeed be a splendid achievement to become able to calculate superspeed, as Professor Brooks has suggested will some day happen. Until we can get the exact formulæ which he foresees, I think we should congratulate him very heartily on providing us with useful data on the subject of superspeed.

Mr. Durfee prefaced the presentation of his written discussion by saying that he wanted to defend the author's ideas as much as possible, and to do this the simplest way was to explain practically all the various theories of the action of the air going around a blade of a propeller, or around the wing of an airplane, which was much the same kind of action.

The screw theory assumed that air is very nearly solid, on account of its inertia. The propeller was assumed to screw through it. Next the additional assumption was made that the air is not solid, that it has some slip. The amount of this slip we knew from experience.

The bat theory as outlined by the author took account of the motion of the air after it left the blade. Mr. Durfee thought the origin of the criticism of this theory was the feeling that if air consisted of a great number of particles, they could not all come down to the surface and bounce back again through the same space. They would interfere with each other. There could not be two directions of flow in the same place. However, he thought that this did not prevent the propeller from being considered as a bat in some other respects. For example, the reacting forces might be substantially perpendicular to the blade surface, as emphasized by the author. Moreover, he thought that the author had performed a useful service in saying that certain kinds of propellers, or fans, actually gave the superspeeds which the author had measured, and in specifying that these speeds were similar to the speeds which one might expect if the blade were in reality acting as a bat.

The partial-vacuum theory was based on experiments which

showed that the partial vacuum on the top of the wing was numerically larger than the positive pressure underneath the wing. The difference in pressure held the wing up. It was not the vacuum, it was not the pressure; but it was the difference between the pressure below and the vacuum above.

The stream-deflection theory assumed that a stream or layer of the air came along and struck the inclined plane, i.e., the propeller blade, and was thus deflected. The trouble with this theory was that the size of the stream was a matter of conjecture. The active stream merged into the surrounding air, and it was customary to assume a stream and guess its proportions and how it was deflected.

Exponents of the momentum theory said: "If the air strikes against the blade, the air is going down behind it; how fast it is going down is told by the slope of the plane." They estimated the weight of the deflected stream and how much power must have been supplied to produce the motion.

What he called the hydraulic theory of sustentation, or thrust, could readily be imagined on the principle of the venturi tube. Where water was going fast through a venturi tube there was a low pressure; where it was going slow there was a high pressure. One could examine the velocity of the air stream where it was rapid on the upper or convex surface of the aerofoil, and where it was slow on the lower or concave surface. Therefore, from a simple theory of hydraulics one could calculate where the pressure was low and where it was high.

The vortex theory assumed that a component of circulation existed around the blade in such a way that the air stream was more rapid on the upper surface of the wing than on the lower surface. A corresponding state of circulation was supposed to be manifested in the form of trailing vortices which had their origins near the ends of the wings, or blades, so as to form endless continuations of the component circulation which existed around the blade. This theory did not explain how such a state of affairs came into existence, and no adequate technique appeared to have been developed for making use of the theory.

The vortices mentioned could be readily seen with the naked eye when the blade, or aerofoil, was working in a dusty or smoky atmosphere. They were formed instantly at the moment when the blade started to move, and the trailing vortices were joined together at the rear extremity by a vortex which was produced by the trailing edge of the blade. This could be seen when the blade started to move.

Remnants of the circulation around the blade could sometimes be detected when the blade was stopped suddenly.

H. F. HAGEN said that the screw theory as mentioned in the paper, with the idea that a screw went through a solid mass either in air or water, had never been used by any designer or scientist. As originally presented by Rankine, it allowed for a certain slip. The term "slip," however, was rather unfortunate. We were accustomed to say that a propeller could not do any work unless it had a certain slip, but it would be much better to say that a propeller could do no work unless it had produced rotation in the direction of the rotation of the screw. That had been proved by a number of investigators and to disregard it would be entirely incorrect.

The various theories enumerated by Mr. Durfee he thought could all be combined under the term "stream-line theory." Professor Brooks' theory did not take account of the discharge side of the propeller, and as the speed of the fluid on the discharge side was certainly faster than the speed of the fluid entering, there could be no continuity. That would require water to be broken up into droplets, or air to behave like a cloud of non-interfering dust particles. The chief objection to this was that air or any other fluid did not work that way. Any one who had ever observed the flow of smoke around the blade would have noticed that there was only one stream line really that touched the blade — the others were formed flowing around smoothly.

Any propeller theory to be complete ought to explain both the action in air and water. Both were fluids and the difference between them was not one of elasticity but of compressibility. Air was compressible, water practically non-compressible. Making due allowance for compressibility, density and viscosity, it should be possible to predict the performance of the air propeller from that of the water propeller. There were questions as to the latter regarding the shape of the stern of the vessel, the free surface of the water, and the bottom, which all combined, so that although the general theory might bring the two together and reconcile the airplane propeller and the water propeller, he doubted very much whether tests on water propellers could ever be used for air propellers, because although the stream lines might be similar, yet it would be impossible to transfer any quantitative results from one to the other.

No. 1643

THE ELASTIC INDENTATION OF STEEL BALLS UNDER PRESSURE

By C. A. Briggs, Washington, D. C.
Member of the Society

and

W. C. Chapin[1] and H. G. Heil[1]
Non-Members

This paper reports the results of experiments recently carried out at the Bureau of Standards, Washington, D. C., in connection with the adjustment and standardization of precision apparatus incidental to the testing of munition gages.

For the case of balls pressing against flat surfaces, which was the one considered in the experiments, the results obtained show that the indentation is not directly proportional to the pressure but to the two-thirds power of the pressure. This is of importance in the design of ball bearings as it indicates what effects are produced on the distribution of the load by slight variations in the size of the balls in a bearing.

The results are given in the form of alignment charts and in both metric and English units.

In the adjustment and standardization of precision apparatus at the Bureau of Standards incidental to the testing of munition gages, the subject of the effect of pressure on the dimensions of steel balls and length standards having rounded ends came up for consideration. After a preliminary study of the matter it was concluded that the distortion of the steel balls between the contacts, and the elastic compression of the portion of the rounded ends not directly in contact with the measuring surfaces, was very small, a conclusion that appeared inconsistent with some of the results that had been obtained in actual measurements. This directed attention from the main portion of the steel ball or rounded surface to the elastic indentation of the surfaces immediately in contact with each other.

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Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

In order to settle the questions arising, experiments were undertaken, and the results obtained form the substance of this report.

2 These experiments, while limited in scope, were so successful in giving consistent results and data of apparently wider application than that originally intended, that it appears desirable to make a brief report summarizing and recording the information obtained.

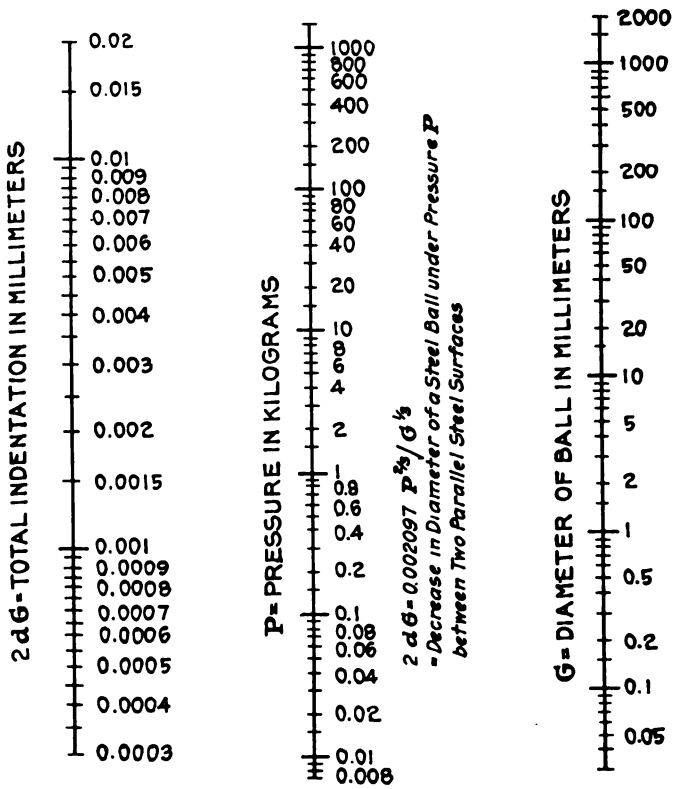

FIG. 1 CHART FOR DETERMINING THE INDENTATION OF STEEL BALLS (METRIC UNITS)

Owing to the fact that the effect of high pressure was of no immediate interest in reference to the problem in hand, and to the fact that to extend the investigation to greater pressures would have required time that was needed for other matters, low pressures only were employed.

3 The maximum pressure used on steel balls against glass plates was 20 lb., which was used on balls ¾ in. and 1 in. in diameter. On

smaller balls the maximum pressure used was 10 lb. The results, therefore, do not represent conditions present when high pressures are used, such as occur in the Brinell hardness test of materials where the stresses are above the elastic limit; or pressures such that the indented area includes a solid angle large enough to invalidate the assumption frequently made when the angle is small that the sine

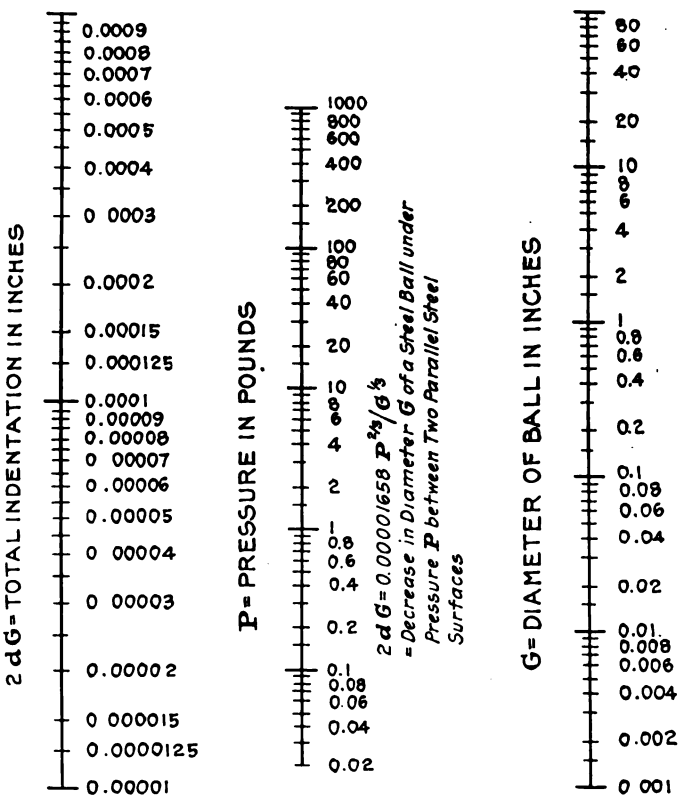

FIG. 2 CHART FOR DETERMINING THE INDENTATION OF STEEL BALLS (ENGLISH UNITS)

and angle are equal. However, the results obtained do give accurate information of the effect of pressures on the measured diameters of spherical surfaces of steel or other materials which are employed in standardizing gages; and also appear to give information of practical value as to what occurs in ball bearings.

4 The experiment was performed by observing and measuring with a micrometer microscope the area of contact made by flat and

spherical surfaces in contact with each other under varying pressures. This area of contact was viewed as the central spot in the Newton's ring system formed when a glass surface was in contact with a polished surface of steel or with another glass surface. The amount of indentation was obtained from the measured diameters by a simple computation, easily derived, which it is not necessary to give here.

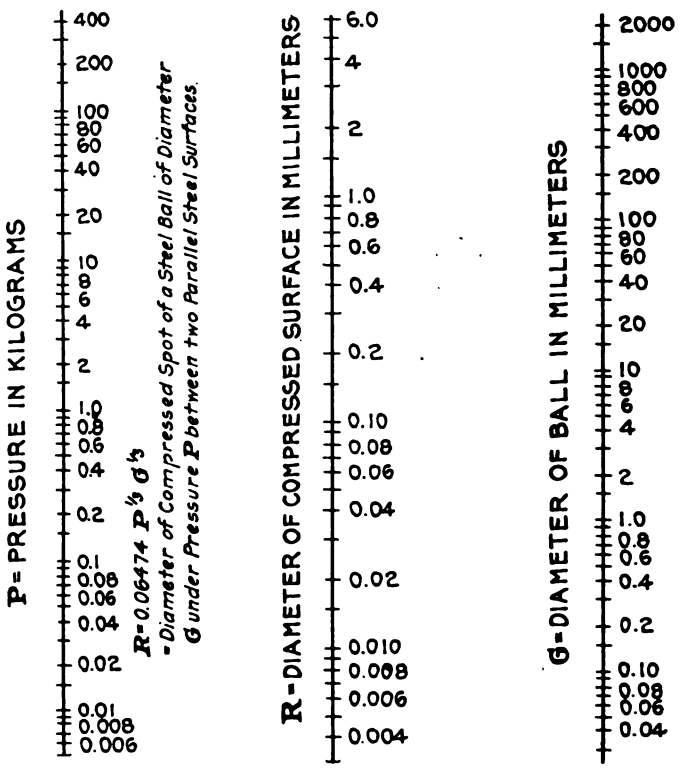

FIG. 3 CHART FOR DETERMINING THE DIAMETER OF THE INDENTED SPOT OF STEEL BALLS (METRIC UNITS)

5 The different combinations of surfaces available for observation and use in the experiments were: a steel sphere pressing against a flat glass surface; a spherical glass surface pressing against a flat steel surface; and a spherical glass surface pressing against a flat glass surface.

6 From an examination of the results for each pair of surfaces in contact plotted on log paper, and from general reasoning based on

the nature of the phenomena, a general equation was worked out for the purpose of correlating all of the results. It is not necessary for present purposes to expand this report by giving all of the various considerations which led to the particular form assumed for this general equation — suffice it to state that after the constants of the general equation had been determined from the experimental data,

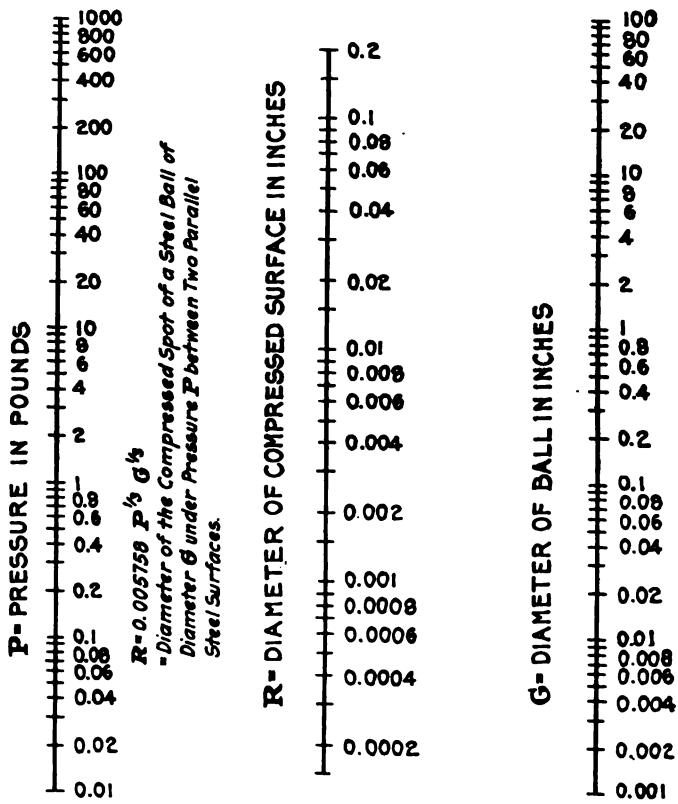

FIG. 4 CHART FOR DETERMINING THE DIAMETER OF THE INDENTED SPOT OF STEEL BALLS (ENGLISH UNITS)

the experimental values were reobtained by computations from the general equation, and the agreement between the computed and experimental values was very good; in fact, the agreement was so satisfactory that it was considered unnecessary to take additional data from the same material, as had been contemplated up to that time.

7 In the case of steel against steel it was of course not possible to observe the area of contact owing to the opaque nature of both contact surfaces, so that the values of steel against steel were obtained by the use of the general formula which had been found to fit all the various surfaces and materials used in the experiments.

8 It will be noted in the equations which follow that a quantity called the "indentation modulus" is used to express the elastic

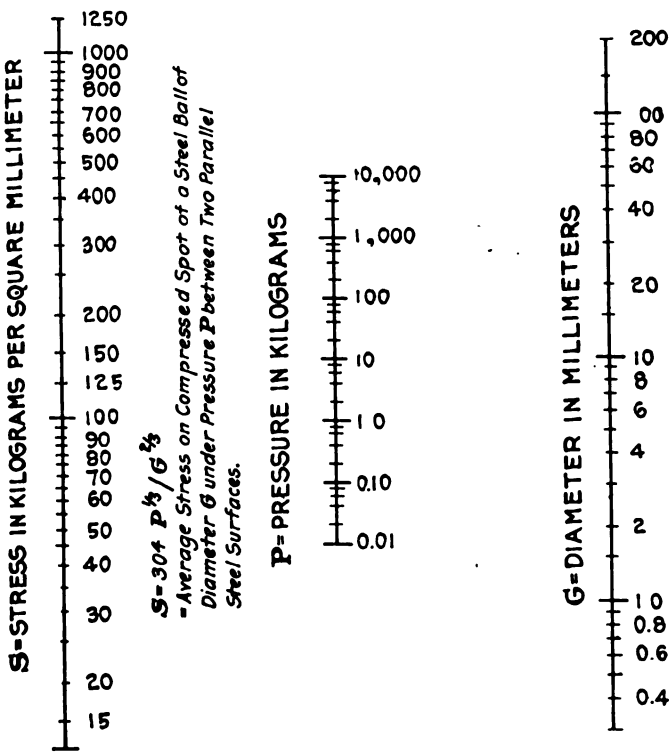

FIG. 5 CHART FOR DETERMINING THE AVERAGE PRESSURE PER UNIT AREA ON THE INDENTED SPOT OF STEEL BALLS (METRIC UNITS)

property which determines the indentation. It was originally intended to use Young's modulus as representing in a general way the elastic properties. However, on looking up the elastic constants of glass it was found that a problem of very similar nature had been worked out by Hertz from theoretical considerations which gave practically the same form of equation as was derived in the present experiments, and in which the elastic property effective in determin-

ing the indentation was found by Hertz to be a function of Young's modulus and Poisson's ratio, and which was called the indentation modulus.

9 It has not been necessary for the present purposes to concern ourselves with the manner in which the indentation is distributed

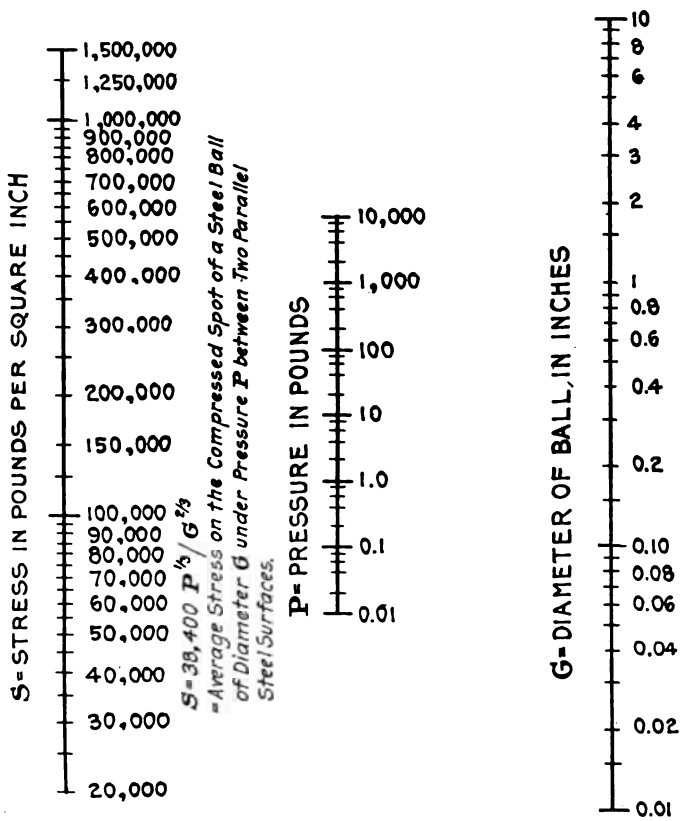

FIG. 6 CHART FOR DETERMINING THE AVERAGE PRESSURE PER UNIT AREA ON THE INDENTED SPOT OF STEEL BALLS (ENGLISH UNITS)

between the surfaces in contact, so no further reference will be made to this subject.

10 A very interesting feature which can be noted on examining the results is that the indentation is not linear with the pressures but is proportional to the two-thirds power of the pressures. This is a fact of important interest in connection with the design of ball bear-

ings, as it indicates what effects are produced on the distribution of the load by slight variations in the size of the balls in a bearing.

11 For steel against steel, which is the case of most general and important interest, the results are given in the form of computation charts, Figs. 1 to 6, by means of which numerical values can be obtained quickly for any particular case covered by the equations. Three of the charts are for metric units and three for English units.

12 In reference to future experiments, those which would appear to be of most practical interest are concerned with the determination of the elastic indentation of spherical surfaces in contact with cylindrical surfaces and cylindrical surfaces against cylindrical surfaces — such as are represented by many forms of ball and roller bearings in every-day use. It would be also of interest to extend the experiments already made by employing higher pressures.

13 The elastic coefficients for the materials used in the experiments of this report were obtained from tabular data. If, in the future, it becomes desirable to obtain information on the indentation of surfaces with great precision, experiments should be performed on materials that have had their properties carefully measured, so as to fix with exactitude the values of Young's modulus and Poisson's ratio for the particular steel and glass used in the experiment.

14 The results of the experiments are summarized in the eight equations which follow.

15 *General Equation for Indentation:*

$$dG = 0.518\,P^{\frac{2}{3}}\left[\frac{G_1 + G_2}{G_1 G_2}\right]^{\frac{1}{3}}\left[\frac{1}{E_1'} + \frac{1}{E_2'}\right]^{\frac{2}{3}} \quad . \quad . \quad . \quad . \quad . \quad [1]$$

where dG = mutual indentation between the surfaces in contact
P = pressure acting between the two surfaces
G_1 and G_2 = radii of curvature of the two surfaces
E_1' and E_2' = indentation moduli of the surfaces G_1 and G_2.

The indentation modulus is given by the expression

$$E' = \frac{E}{1 - u^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

where E = Young's modulus and u = Poisson's ratio. The constant 0.518 is the same for both metric and English units when either are used consistently throughout the formula.

16 *Indentation of Steel Balls Between Flat Steel Surfaces.* For metric units the indentation is given by the equation

$$2\,dG = 0.00210\frac{P^{\frac{2}{3}}}{G^{\frac{1}{3}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

where 2 dG is the indentation in millimeters from both sides of the ball. For English units the equation is

$$2\,dG = 0.0000166\,P^{\frac{2}{3}}/G^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

where 2 dG is given in inches.

17 *Diameter of Area of Contact Between the Surfaces, Steel Against Steel.* For metric units,

$$R = 0.0647\,P^{\frac{1}{3}}G^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

where R is the diameter of the spot in millimeters. For English units,

$$R = 0.00576\,P^{\frac{1}{3}}G^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [6]$$

where R is given in inches. If the general equation is desired for R it can be derived easily from Equation [1].

18 *Average Pressure Over the Area of Contact, Steel Against Steel.* For metric units,

$$S = 304\,P^{\frac{1}{3}}/G^{\frac{2}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [7]$$

where S is given in kilograms per square millimeter. For English units,

$$S = 38{,}400\,P^{\frac{1}{3}}/G^{\frac{2}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [8]$$

where S is given in pounds per square inch. If the general equation for S is desired it can likewise be developed from Equation [1].

19 *Computation Charts.* Means for graphically solving the preceding equations are shown in the accompanying charts, Figs. 1 to 6. A straight line placed across any of the charts will strike readings on the vertical scales which are a solution of the corresponding equation. With these charts, when any two of the three quantities of the equation are given, these quantities will establish two points which determine a straight line, and the value of the third quantity will be given by the intersection of the straight line with the corresponding vertical scale.

DISCUSSION

THE AUTHOR. In reply to a question asked by Arthur M. Greene, Jr., I would say that while the pressure employed in the experiments was never greater than 20 lb., I believe that the formula derived will apply to much higher pressures.

It should be stated that these experiments were made in the midst of war when time was at a premium and when results were the only matters of interest. In starting the gage work the question

of the effect of pressure was constantly arising in the measurements made in the shop and in the laboratories, and while it now appears that experiments of this nature had been made in previous work, it was not familiar to those needing it at that time. Experimental work was first started in a very extemporaneous way, but the results proved to be very satisfactory and approximate values were obtained in very short order.

Reference has been made in the paper to the formula of Hertz. Since the experimental work of this paper was done, and after the gage work was well started, the work of Hertz was examined in another reference with the following interesting facts developing:

Taking the experimental constant developed in the paper and altering the equation to correspond to a sphere pressing against a flat surface, where the sphere and the flat surface are of the same material, and comparing the coefficient of the equation with the coefficient of the similar equation deduced by Hertz from theoretical considerations, there results:

Value of coefficient determined from these experiments.....	0.8229
Value of theoretical coefficient deduced by Hertz.....	0.8255

This agreement between the two coefficients, experimental and theoretical, is well within one-half of one per cent.

Previous to the experiments of this paper it appears that experiments were attempted in using steel but had to be given up. In view of the fact that absolutely no difficulty was experienced in the present instance it is hard to understand what the trouble was.

A paper by Henry Hess,[1] to which I have been referred, gives a translation of an article by Professor Stribeck, in which the following statement is made:

> To determine the influence of the elastic modulus, he pressed a steel lens against the plane surfaces of various materials, but encountering difficulties of observation he gave up the experimental proof.

This work suggests two things of importance: First, that the results of elastic indentation deduced from the theoretical considerations, as was done by Hertz, can be depended on to give practical results; second, from the directness with which the experiments were carried out it appears that in practice for new forms of the problem it may be found easier to make experiments and develop empirical equations from the data obtained than to handle the mathematical difficulties.

[1] Trans. Am. Soc. M. E., vol. 29 (1907), p. 421.

No. 1644

ELECTRIC HEATING OF MOLDS

By Harold E. White, Ampere, N. J.
Member of the Society

In forming parts made from hard rubber and the various phenolic condensation products now available, the standard procedure has been to employ metal molds filled with the material which are placed between steam-heated plates attached respectively to the upper and lower platens of a hydraulic press.

Difficulties encountered by the author in the use of this method led him to devise the one described in the paper, in which the heating is done electrically. Briefly, it consists in magnetizing the molds with alternating current at 60 cycles. As the molds are of steel and generally hardened, they heat up rapidly due to induced electric currents and also in part to hysteresis losses.

Various advantages of the new method are pointed out, and it is stated that it can probably be utilized to advantage in the production of die castings of readily fusible metal, and also in drawing the temper of hardened-steel parts.

SYNTHETIC molding materials are being used on an increasingly extensive scale not only for parts of electrical machinery, but for many other articles of usefulness. It is the purpose of this paper to describe a novel method for applying heat to the molds in which such parts are formed which the writer believes will be of general interest and of considerable utility under certain conditions.

2 The earliest example of such a material is perhaps hard rubber or vulcanite. More recent examples are the phenolic condensation products sold under various trade names. All of these materials are alike in that a moderate degree of heat causes them to soften sufficiently to take the form of the mold, while a higher degree of heat causes them to undergo chemical changes that harden them into a highly resistant condition. In general, the phenolic condensation products are superior to the older rubber products, except where a high degree of elasticity is essential. The phenolic condensation products are much more resistant to chemical action and in some preparations are much stronger mechanically.

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3 Manufacture of parts made of this material on a small scale under the observation of the writer led to the development of the new method of production which is described. While it is not believed that this method can replace the methods used in factories which specialize on these materials, it would appear, nevertheless, that it can be used with success in almost any machine shop equipped with a hydraulic press, or even an arbor press if the articles are small, provided alternating current is available.

4 At first an attempt was made to use the standard method of production, which was to place the filled molds between two steam-heated plates attached respectively to the upper and lower platens of a hydraulic press. Live steam at about 110 lb. per sq. in. was admitted to these plates until the pieces were fully hardened. Then cold water was circulated through the same plates until the mold was cold, after which the mold was taken out and refilled for another piece.

5 Under these conditions production was slow and frequently interrupted altogether. The slowness of production was due to the fact that heat was not transmitted rapidly enough from the hot plates to the mold because the steam was often wet and the plates had a lower temperature than the boiler pressure would indicate. These difficulties were accentuated by the fact that most of the molds were long and slender, so that they had but a small part of their surface in contact with the hot plates and a large part of their surface in contact with the air. The heating and cooling of the fittings alternately carrying the steam and the cooling water resulted in frequent leaks, especially in the flexible piping, the use of which was necessitated by the movement of the upper platen of the press.

6 During one of these periods of interruption recourse was had to a method of electrical heating with such good results that the use of steam was abandoned altogether. In brief, the method consisted in magnetizing the molds with alternating current at 60 cycles. As these molds are always made of steel and generally hardened, they will heat up rapidly under these conditions due to induced electric currents in the various parts of the molds and also in some measure to hysteresis losses, especially in the hardened parts.

7 The method as at first used was simple in the extreme. The coil was made of 100 turns of No. 6 asbestos-covered wire and when in operation its terminals were connected by a switch directly to the 220-volt supply line. With molds weighing 10 to 15 lb. a curing temperature could be reached, starting cold, in from 3 to 5 min. It

should be understood that under the conditions of working the magnetizing coil remains quite cool.

8 The heat is developed in the interior, though mostly near the surface, of the molds. If the current is left on indefinitely a temperature destructive to the molding material results. This necessitates some way by which a definite result may be secured. Generally it is sufficient to make trial pieces, noting the time of heating of each by a watch or clock. After observing the right time, it can be repeated indefinitely for other pieces. A good method of gaging the temperature of the molds is to observe the color of sulphur when melted in contact with the mold. The brick-red color which sul-

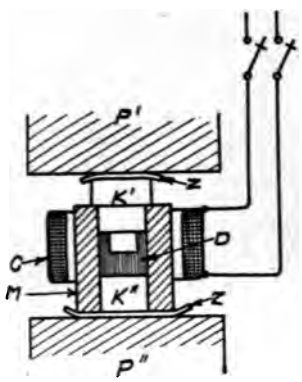

FIG. 1 ELEMENTARY ARRANGEMENT OF HEATING COIL

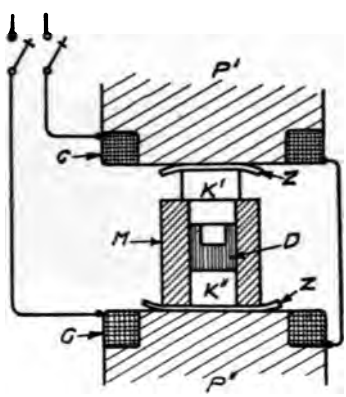

FIG. 2 IMPROVED ARRANGEMENT WITH COILS ABOVE AND BELOW

phur shows at 180 deg. to 200 deg. cent. gives a good indication, but it is hard to keep the sulphur in place. A better material is a cane-sugar syrup with a little blue litmus, which clings to the hot molds and chars to a tobacco-brown when the temperature limit has been reached.

9 When a sufficient temperature has been reached the switch is opened and the mold cools off slowly, during which time the final hardening of its contents takes place.

10 A study of the heating action in detail is interesting. Referring to Fig. 1, P' and P'' are the cast-iron platens of the press, M the matrix, and K' and K'' the plugs by which the molding material D is pressed in the matrix. C is the current-carrying coil. Since the magnetic field is the means of carrying the energy to the mold, it will be seen by those familiar with electromagnetism that the part

of the mold in the plane of the coil heats most rapidly. The ends of the mold in contact with the platens lose heat rapidly, so that it was found well to protect them against such loss by asbestos or pasteboard sheets at Z. Next, several coils of different proportions were made, long ones for the longer molds and flatter ones for the shorter ones.

11 It was found inconvenient to lift the hot molds from the interior of the coils, so a further improvement was made in which the

FIG. 3 HYDRAULIC PRESS FITTED WITH COILS AS SHOWN IN FIG. 2

coils were subdivided into two halves and mounted as shown in Fig. 2, in which letters designate the same parts as in Fig. 1. This arrangement gives good heating throughout the mold regardless of the shape. In fact, there is a little greater heating at the ends, which compensates for loss by conduction. The plates P', P'' were fitted with laminated-iron sections so that a path for the magnetic flux in them, which would not develop heat, could be provided. Fig. 3 is a photograph of the press fitted with these coils. It is evident that the molds could be

put into or removed from the press thus fitted as readily as from an ordinary press.

12 In all of these arrangements the magnetic return circuit consists of leakage through the air and through the massive parts of the press, in all of which the magnetism is so diffused that the energy loss is small. This is clear from the fact that such losses are a function of the square of the magnetic density and the electrical conductivity of the material. Cast iron being of low conductivity, losses in the heavy parts of the press are necessarily very small. Cast iron would not be a good material from which to make the molds. It is evident that the thermal efficiency of this method is comparatively high. The writer has good reason to believe that more than half of the heat which is developed makes its appearance in the mold.

13 By the induction method of heating it is possible to pile several thin molds on top of each other and heat them all at once. This is not possible by any other method. By this means one press can be made to produce several articles simultaneously.

14 In making molded insulation the cost of molds is frequently very great. By the induction method of heating the cheapest possible mold can be used, since it is never necessary to so shape it as to admit steam to it, or so as to favor the flow of heat into it from any external source.

15 Many electrical engineers would regard the low power factor at which such devices operate as a serious drawback. However, the writer regards it as an important advantage in that a steadying effect on the circuit is produced, so that whether a large mold or a small mold or no mold at all is placed in the coil, no harmful result will follow, the large size of wire used being sufficient for the current at all times. Measured up in terms of value received for the outlay and freedom from trouble and general convenience, the process was entirely satisfactory. A press having a better magnetic circuit which would have operated at a power factor comparable to that of an induction motor could have been made at a greater cost, but the extra cost would have exceeded the saving possible during the time the above apparatus was in use, which was about one year.

16 It is believed that other uses might be made of this process; for example, die castings of readily fusible metal might be made economically on a small scale; or hardened-steel parts might be tempered, in which case the temper could be drawn without overheating sharp angles and cutting edges.

No. 1645

STRESSES IN MACHINES WHEN STARTING OR STOPPING

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For the intelligent determination of the dimensions of machine parts it is necessary that the forces acting thereon be known. The calculation of these forces follows at present one of two methods. The first assumes a state of equilibrium for the machine, which, however, exists only when the machine runs at constant speed or is at rest. In the second the machine is considered to consist of rigid parts, but their acceleration at start or stop is considered. Neither of these methods leads to even approximately correct results. A new method for the correct evaluation of the forces acting on machine parts during start or stop is developed, and illustrated by application to a vertical geared hydraulic hoisting machine. It is shown that the stresses during start or stop depend on the inertia and elasticity of the parts, their distribution throughout the system, and on the magnitude and nature of the accelerating force. Vibrations at start or stop always occur, but whether they are pronounced and give rise to dangerous stresses depends to a very great extent on the character of the accelerating force.

1 INTRODUCTION

A MACHINE is a system of correlated parts so arranged that the application of one or more forces — which for distinction we shall call the motive forces — to certain of the machine parts will cause motion and overcome resistances due to frictional forces and loads applied to other parts.

2 A cycle of operation of a machine can be divided into three more or less distinct periods, namely, the start, run at constant speed, and the stop. Equilibrium between the motive force and the resistances exists only when the machine parts run at constant speed, and the forces which then act on them are easily determined by the known processes of statics. During stop or start the forces acting on the machine parts exceed those existing in the state of equilibrium by the amounts necessary for their acceleration.

3 If we had to deal with perfectly rigid bodies in our machines, that is, if we had to consider inertia only, the determination of these

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forces by the application of the dynamics of rigid bodies would present no difficulty whatsoever. As a matter of fact, however, the machine parts have not only inertia but also elasticity. By virtue of the latter they are capable of sustaining deformations, and provided that the parts have not been stressed above the elastic limit, there is stored in them an amount of energy equal to the energy that produced the deformation. This energy is called the potential energy. At the start or stop, then, the work done by the motive force goes into three parts: one part overcomes the resistance, a second goes into kinetic energy, and a third into potential energy.

4 The extent to which each of these forms of energy participates in the work done by the motive force changes from instant to instant. In view of these complicated phenomena it is, to say the least, idle to suppose that the calculations of machine parts can be based on the forces as they exist in the state of equilibrium plus an arbitrary allowance for so-called impact, which in most cases is not even there. It is therefore the object of this paper to present a method whereby the forces and phenomena which occur during start or stop may be determined with a degree of accuracy more than sufficient for technical purposes.

5 Although in problems of this kind a fairly extensive mathematical apparatus cannot altogether be avoided, it has been reduced considerably by the application of the so-called theory of normal coördinates. A detailed exposition of this theory cannot here be given and the explanations have been limited to the extent necessary for a complete understanding. This is somewhat unfortunate owing to its very generalized treatment in books, such as Rayleigh's Theory of Sound, Routh's Rigid Dynamics, or Thomson and Tait's Treatise on Natural Philosophy.

6 Since a mere theoretical treatise would be unprofitable, it is here proposed to determine the motion and forces when starting the hydraulic machine shown diagrammatically in Fig. 1. In the actual design of this machine it became necessary, for reasons of control, to allow for comparatively large hydraulic losses. In other words, while the water pressure necessary to balance the load plus the mechanical frictions amounted to 183 lb. per sq. in., the pressure supplied by the pumps was 260 lb. per sq. in. At the start, therefore, there was an excess of pressure of 77 lb. per sq. in., and since the piston masses were comparatively small, very little of it would be absorbed in their acceleration. It was consequently expected that ropes and other parts would have to sustain heavy loads during the start.

For that reason the following calculations were undertaken, and they are here reproduced only with such modifications as make them more suitable for the purposes of this paper. Dynamically the system is quite interesting, since the load A and piston D move in a straight line; the stationary sheave B has rotation only, and the traveling sheave C rotation as well as translation.

7 Strictly speaking, all of our machine parts are elastic, but fortunately there are always a few which have elasticity to such a predominating degree that the other parts in comparison therewith may be considered to be rigid. Also, very frequently those members which are predominatingly elastic have negligible mass. Thus, any machine may be approximated by a system of parts, of which some have elasticity and others inertia only. In the machine of Fig. 1, for instance, it is at once evident that we shall consider the ropes ab, cd, and ef as the only elastic members and therefore as the seat of potential energy. Their mass is negligible as compared with the mass of the other machine parts and may be neglected. The remainder of the parts, that is the load A, sheaves B and C, piston and piston rod will be considered rigid and therefore as the seat of kinetic energy.

8 With reference to Fig. 1, denote by —

m_1	the mass of the load A
m_1g	the weight of load A in lb. (g = acceleration of gravity)
m_2	the mass of the stationary sheave B reduced to the radius O_2b; m_2 being that mass which, if placed at a radius of O_2b ft., will have a moment of inertia in respect to the axis of rotation equal to the moment of inertia of the sheave
m_3	the mass of the traveling sheave C reduced to the radius O_3d, that is, the mass m_3 placed at a radius of O_3d ft. will have a moment of inertia in respect to the axis of rotation equal to that of the sheave
m_3'	the mass in the ordinary sense of sheave C
$m_3'g$	the weight of sheave C
m_4	the mass of piston and piston rod
m_4g	the weight of piston and piston rod
s_1 and $(s_1)_0$	the displacement in ft. of the load A at the times t and $t = 0$, respectively
s_2 and $(s_2)_0$	the circumferential displacement in ft. of points b and c of sheave B at the times t and $t = 0$, respectively
s_3 and $(s_3)_0$	the circumferential displacement in ft. of points d and e of sheave C at the times t and $t = 0$, respectively
s_4 and $(s_4)_0$	the displacement in ft. of the piston and the parts rigidly connected thereto at the times t and $t = 0$, respectively
v_1 and $(v_1)_0$	the velocity in ft. per sec. of the load A at the times t and $t = 0$, respectively

v_2 and $(v_2)_0$	the circumferential velocity in ft. per sec. of points b and c of sheave B at the times t and $t = 0$, respectively
v_3 and $(v_3)_0$	the circumferential velocity in ft. per sec. of points d and e of sheave C at the times t and $t = 0$, respectively
v_4 and $(v_4)_0$	the velocity in ft. per sec. of the piston at the times t and $t = 0$, respectively
P	the net force in lb. which the piston at the time t exerts on the piston rod
F_2 and F_3	the mechanical frictions in lb., measured at the radii O_2b and O_3d, respectively, due to the rotation of sheaves B and C in their bearings
S_1, S_2, S_3	the forces with which at the time t the ropes ab, cd and ef respectively react on the machine parts which they connect
$(S_1)_0$, $(S_2)_0$, $(S_3)_0$	the values of the above forces at the time $t = 0$
a_1, a_2, a_3	the elongation in ft. which ropes of the free lengths ab, cd and ef suffer if acted upon at their ends by a force of 1 lb.

9 Strictly speaking, the quantities a_1, a_2, a_3 are not constants, but vary as the free lengths of the ropes ab, cd and ef change with the motion of the machine. As a rule, however, the starting or stopping periods are sufficiently short so that no appreciable error is made by using the quantities a_1, a_2, a_3 as if they were constants. Where this is not the case, these values should be based on the average free lengths of the ropes during the period for which the calculations are to be made.

10 The displacements s_1, s_2, s_3 and s_4 of the rigid machine parts will be measured from the position which they would assume if the elastic members (here the ropes ab, cd and ef) were permitted gradually to contract until they were free from stress. The initial displacements $(s_1)_0$, $(s_2)_0$, $(s_3)_0$ and $(s_4)_0$ therefore correspond to the static deformation (here the static elongation of the ropes) under the influence of the external forces acting on the machine at the time $t = 0$.

11 The direction in which a displacement will be counted positive may be arbitrarily chosen. If, however, once selected for any one of the machine parts, the positive direction for the others is necessarily that direction in which they tend to move if a positive displacement is given to the former. Thus, if in Fig. 1 the arrow 1 is the positive direction for the displacement of the load A, the positive directions for the displacements of the other rigid machine parts will be according to the arrows 2, 3, and 4. External forces will be counted positive or negative, depending on whether they tend to displace the part on which they act in the positive or negative direction.

12 The forces S_1, S_2, S_3 are internal forces corresponding to the stresses in the ropes and occur in pairs of opposite direction. They are given the positive or negative sign according to convention and not by comparison of their direction with the arrows 1, 2, 3, and 4

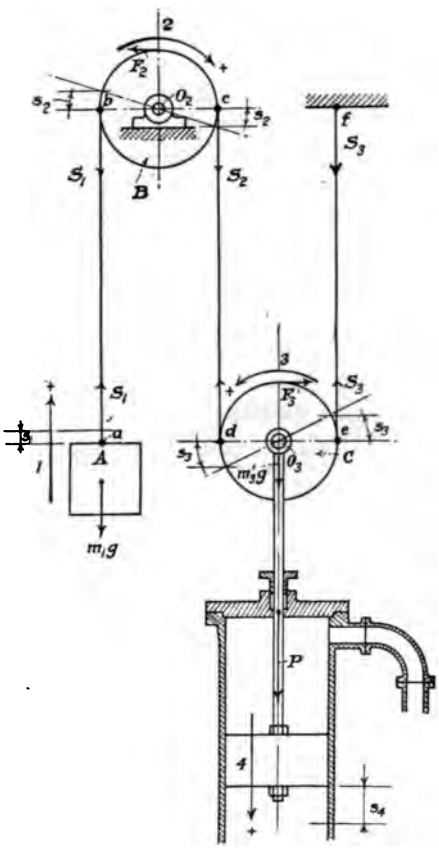

FIG. 1 DIAGRAM OF HYDRAULIC MACHINE

of Fig. 1. In the present case a positive value of the forces S_1, S_2, S_3 will indicate tension and a negative value compression. If tension, they will have the directions shown in Fig. 1. Having here to deal with ropes, our equations of course lose their validity as soon as the values for S_1, S_2, S_3 become negative.

13 In regard to the evaluation of the mechanical frictions F_2 and F_3, the following is to be remarked. Considering in particular F_3, it is proportional to the force with which the sheave C is pressed

against the axle O_3, around which it rotates (Fig. 1). The sheave C is acted upon by the forces S_2 and S_3 and also moves with the velocity of translation v_4. The force with which it is pressed against the axle is therefore equal to $S_2 + S_3$ plus the force $m'_3\, dv_4/dt$ necessary to impart to its mass m'_3 the acceleration dv_4/dt. It will thus be seen that generally the frictions are functions of the motion of the machine. Their exact evaluation, even under the assumption of a constant coefficient of friction, leads to equations which cannot be integrated. As a rule, however, the frictions amount only to fractions of the forces acting on the machine parts and no material error will be made by considering them constant during the whole starting or stopping period, and of the same magnitude as when the machine runs at full speed.

14 Other difficulties in dealing with mechanical frictions are due to the fact that the direction in which they act depends on the direction in which motion takes place. Fortunately, during the stopping or starting of machines there is normally no reversal of the direction in which each part moves. Thus, in our calculations for the start of the hydraulic machine, Fig. 1, the frictions F_2 and F_3 can be treated as external forces of constant magnitude and of the direction shown in the figure.

2 THE ENERGY EQUATION OF A MACHINE ACTUATED BY EXTERNAL FORCES

15 According to the deformations existing in the elastic machine members at the time $t = 0$, there is stored in them a certain amount of potential energy, which will be denoted by V_0. At the time t other deformations have occurred and if V denotes the potential energy corresponding thereto, the gain in potential energy at the time t will be expressed by $(V - V_0)$ ft-lb.

16 If at the time $t = 0$ the system is in motion, it possesses in virtue thereof the initial kinetic energy T_0. At the time t the kinetic energy will be T and the gain therefore is expressed by $(T - T_0)$ ft-lb.

17 Denoting by W the rate of work performed by the external forces acting on the system during any instant from $t = 0$ to $t = t$, we have, according to dynamics,

$$\left.\begin{array}{l}\text{Gain in kinetic energy plus}\\ \text{gain in potential energy}\end{array}\right\} = \begin{array}{l}\text{total work done by external forces in}\\ \text{time interval from } t = 0 \text{ to } t = t\end{array}$$

and hence

$$(T - T_0) + (V - V_0) = \int_0^t W dt \quad \ldots\ldots\ldots\ldots [1]$$

This is the general energy equation and its application to machines merely requires the derivation of the expressions for T, V, and W.

18 The kinetic energy of a system is the sum of the kinetic energies of its constituent parts and thus we obtain for the hydraulic machine, Fig. 1:

For the load A, m_1 = mass and v_1 = impressed velocity, hence kinetic energy = $\frac{1}{2} m_1 v_1^2$ ft-lb.

For sheave B, m_2 = reduced mass and v_2 = velocity impressed thereon, hence kinetic energy = $\frac{1}{2} m_2 v_2^2$ ft-lb.

For sheave C, total kinetic energy = kinetic energy due to rotation at the circumferential speed v_3 plus kinetic energy due to translation at the piston speed v_4. The speed v_3 is impressed on its reduced mass m_3, and v_4 on its mass in the ordinary sense, m_3', hence the kinetic energy = $(\frac{1}{2} m_3 v_3^2 + \frac{1}{2} m_3' v_4^2)$ ft-lb.

For the piston and piston rod, m_4 = mass and v_4 = impressed velocity, hence kinetic energy = $\frac{1}{2} m_4 v_4^2$ ft-lb.

Summing up the above quantities, we obtain

$$T = \frac{1}{2} \{m_1 v_1^2 + m_2 v_2^2 + m_3 v_3^2 + (m_3' + m_4) v_4^2\} \quad \ldots\ldots [2]$$

19 The potential energy V has its seat in the elastic members of the system and is the work necessary to bring about the elongations which the ropes ab, cd and ef suffer at the time t. As to the rope ab, its end b at the time t has moved the distance s_2 and its end a the distance s_1. The elongation at the time t consequently is $(s_2 - s_1)$ ft., by virtue of which it reacts on the load A and the sheave B with a force S_1. We have denoted by a_1 ft. the elongation which a rope of the free length ab suffers if acted upon at its ends by a force of 1 lb. The force S_1 necessary to bring about an elongation of $(s_2 - s_1)$ ft. is therefore expressed in magnitude and direction by

$$S_1 = \frac{s_2 - s_1}{a_1} \text{ lb.} \quad \ldots\ldots [3a]$$

20 In writing down equations similar to [3a], care should be taken so that whatever displacements we choose to give to the points a and b, tension must always be reflected by a positive value of S_1 and compression (supposing we are dealing with a member capable of sustaining compressive stresses) by a negative value.

21 The potential energy stored in the rope ab is the work necessary to produce the elongation $s_2 - s_1$, and is equal to the product of

one-half the elongation into the force to produce the elongation. Thus, the potential energy of the rope ab at the time t will be expressed by

$$\tfrac{1}{2}(s_2 - s_1)\, S_1 \text{ ft-lb.};$$

or, substituting for S_1, by

$$\frac{(s_2 - s_1)^2}{2\,a_1} \text{ ft-lb.} \qquad [4a]$$

22 For the rope cd the displacement of the end d at the time t is $(s_3 + s_4)$ ft., namely, the sum of a displacement s_3 on account of rotation and a displacement s_4 due to the translation of sheave C. The end c has moved through the distance s_2 and the elongation of the rope will be $(s_3 + s_4 - s_2)$ ft., by virtue of which it reacts on sheaves B and C with a force S_2. Since a rope of the free length cd when acted upon at its ends by a force of 1 lb. sustains an elongation of a_2 ft., we have

$$S_2 = \frac{s_3 + s_4 - s_2}{a_2} \text{ lb.} \qquad [3b]$$

whence the potential energy will be

$$\tfrac{1}{2}(s_3 + s_4 - s_2)\, S_2 \text{ ft-lb.}$$

or when substituting therein for S_2,

$$\frac{(s_3 + s_4 - s_2)^2}{2\,a_2} \text{ ft-lb.} \qquad [4b]$$

23 As to the rope ef, its end e has moved at the time t through the distance $(s_3 - s_4)$ ft., its end f is stationary, whence the elongation will be $0 - (s_3 - s_4) = (s_4 - s_3)$ ft. The force S_3 with which it reacts on sheave C will be expressed by

$$S_3 = \frac{s_4 - s_3}{a_3} \text{ lb.} \qquad [3c]$$

and the potential energy by

$$\tfrac{1}{2}(s_4 - s_3)\, S_3 = \frac{(s_4 - s_3)^2}{2\,a_3} \text{ ft-lb.} \qquad [4c]$$

The potential energy of the machine at the time t is the sum of the potential energies of its constituent parts. Hence, by adding the quantities [4a], [4b] and [4c], we obtain

$$V = \frac{1}{2}\left\{\frac{(s_2 - s_1)^2}{a_1} + \frac{(s_3 + s_4 - s_2)^2}{a_2} + \frac{(s_4 - s_3)^2}{a_3}\right\} \qquad [5]$$

24 The external forces acting on the hydraulic machine, Fig. 1, consist of $-\,m_1g$, the weight of the load A; $+\,m_2'g$, the weight of

sheave C; $+m_4g$, the weight of piston and piston rod; the frictional forces $-F_2$ and $-F_3$; and the motive force $+P$.

25 In a system the rate at which work is performed by the external forces is the sum of the rate of work of the individual forces, the latter being the product of the force into the velocity of its point of application. Thus, we easily derive

$$W = -m_1g_1v_1 - F_2v_2 - F_3v_3 + (m_3'g + m_4g + P)v_4 \ldots\ldots [6]$$

Substituting in [1] for T, V and W from [2], [5] and [6], the energy equation for the hydraulic machine will be expressed by

$$\left.\begin{aligned} &\tfrac{1}{2}\{m_1v_1^2 + m_2v_2^2 + m_3v_3^2 + (m_3' + m_4)v_4^2\} - T_0 \\ &\quad + \frac{1}{2}\left\{\frac{(s_2 - s_1)^2}{a_1} + \frac{(s_3 + s_4 - s_2)^2}{a_2} + \frac{(s_4 - s_3)^2}{a_3}\right\} - V_0 \\ &\qquad = \int_0^t \{-m_1gv_1 - F_2v_2 - F_3v_3 + (m_3'g + m_4g + P)v_4\}dt \end{aligned}\right\} \ldots [7]$$

The quantities T_0 and V_0 may be obtained from [2] and [5] by substituting therein initial velocities and displacements for velocities and displacements at the time t. However, these quantities are of no interest to us and are merely carried along since without them [7] would not be correct.

3 RIGID AND RELATIVE MOTION

26 During stop or start the tensions in ropes ab, cd and ef vary from instant to instant. Considering in particular the rope ab, an increase in tension is accompanied by an increase in elongation, causing the points a and b to recede from each other. If the tension decreases, the rope contracts and points a and b approach each other. These varying elongations, however, are merely varying increments in the free length of the rope. Thus, the motion of points a and b, that is, the motion of the load A and the circumferential motion of point b on sheave B, consists of two components. One of these is a motion — common to both — wherein the linear distance between the points a and b remains unchanged and equal to the free length of the rope. The second is a motion superposed on the former and corresponds to the varying elongations due to the rope's elasticity. The same applies to the motions of the other machine parts.

27 In problems of the kind with which we here are concerned, it is simpler to determine the above two components separately and to sum them up if it is desired to know the absolute motion. For distinction, the first-mentioned component will be called the rigid, and the last-named the relative, motion. The rigid motion of a machine

then is defined to be the motion which it would have under the influence of the external forces if all of its parts were rigid. Applied to the hydraulic machine of Fig. 1, wherein the parts A, B, C, and D already have been assumed to be rigid, the rigid motion will be its motion if in addition the ropes ab, cd and ef are non-extensible.

28 The relative motion of a machine will be defined to be the motion of its parts relative to the rigid motion. This component corresponds to the deformations of those members of a machine which are considered to be elastic and is for our purposes the most important. The absolute motion of a machine part will be the algebraic sum of its rigid and relative motions.

29 The object next to engage our attention consists in the determination of the energy equations for both the rigid and relative motions. For this purpose we denote by:

σ_1 and v_1 the rigid displacement and velocity respectively of the load A

σ_2 and v_2 the rigid circumferential displacement and velocity, respectively, of points b and c of sheave B

σ_3 and v_3 the rigid circumferential displacement and velocity, respectively, of points d and e of sheave C in their rotation about O_3

σ_4 and v_4 the rigid displacement and velocity, respectively, for the piston and the machine parts rigidly connected thereto.

30 If all of the machine parts are rigid and therefore suffer no deformation, there can of course be no potential energy. The energy equation for the rigid motion can consequently be derived from [7] by equating to zero all terms corresponding to the potential energy, i.e., the terms having the coefficients a_1, a_2, a_3, and by replacing absolute displacements and velocities in the remainder by the corresponding quantities in the rigid motion. This gives

$$m_1v_1^2 + m_2v_2^2 + m_3v_3^2 + (m_3' + m_4)\,v_4^2 - 2\,T_0$$
$$= 2\int_0^t \{-m_1g_1v_1 - F_2v_2 - F_3v_3 + (m_3'g + m_4g + P)\,v_4\}dt \quad [8]$$

Moreover, if the ropes of the hydraulic machine in Fig. 1 are non-extensible, there exist between the rigid displacements and velocities the following relations:

$$\left.\begin{array}{l}\sigma_1 = \sigma_2 = \sigma_3 + \sigma_4 \\ \sigma_3 = \sigma_4\end{array}\right. \quad \text{and} \quad \left.\begin{array}{l}v_1 = v_2 = v_3 + v_4 \\ v_3 = v_4\end{array}\right\} \quad [9]$$

31 By means of the above the energy equation for the rigid

motion of the machine can be expressed as a function of the rigid displacement and velocity of any one of its parts, say of the piston. Deriving from [9]

$$v_1 = v_2 = 2\,v_4; \quad v_3 = v_4$$

and substituting in [8] we obtain

$$\{4\,(m_1 + m_2) + m_3 + m_3' + m_4\}\,v_4^2 - 2\,T_0$$
$$= 2\int_0^t \{P - 2\,F_2 - F_3 - g\,(2\,m_1 - m_3' - m_4\}v_4\,dt \,.\,.\,[10]$$

32 It will be recognized that the expression between parentheses in the left-hand member of [10] represents the aggregate mass of the machine reduced to the piston. It is that mass which, if concentrated at the piston and moving at the rigid piston velocity v_4, will have the same kinetic energy as has the machine in its rigid motion. The expression between parentheses in the right-hand member of [10] represents the force reduced to the piston. It is that force which, if acting on the piston, would do work at the same rate as do the actual forces in the rigid motion of the machine.

33 As to the relative motion, we should, strictly speaking, introduce new coördinates such as ϵ_1, ϵ_2, ϵ_3, ϵ_4, to denote the displacements therein. The absolute displacements s_1, s_2, s_3 and s_4 being the sum of the rigid and relative displacements, will then be expressed by

$$s_1 = \sigma_1 + \epsilon_1; \quad s_2 = \sigma_2 + \epsilon_2; \quad s_3 = \sigma_3 + \epsilon_3; \quad s_4 = \sigma_4 + \epsilon_4$$

Substituting, however, for s_1, s_2, s_3, s_4, in [3*a*], [3*b*] and [3*c*], and employing the relations [9], we find

$$S_1 = \frac{\epsilon_2 - \epsilon_1}{a_1}; \quad S_2 = \frac{\epsilon_3 + \epsilon_4 - \epsilon_2}{a_2}; \quad S_3 = \frac{\epsilon_4 - \epsilon_3}{a_3}$$

and see that S_1, S_2, and S_3 remain the same irrespective of their being expressed in absolute or relative displacements. As in the rigid motion the points *a* and *b*, *c* and *d*, *e* and *f* (Fig. 1) are supposed to be connected by non-extensible ropes, there can of course be no elongations and therefore no stresses nor forces S_1, S_2, S_3. This is reflected in the above expressions for S_1, S_2, S_3 by the vanishing therein of the rigid displacements.

34 Less evident is the fact that the energy equation for the relative motion is the same as [7], if we replace therein the absolute by the corresponding relative velocities and displacements. Proof for this statement can be given in the same manner as the demonstration in handbooks on dynamics, that the general energy equa-

tion [1] applies in the same form to the absolute motion as well as to the motion of the system relative to the motion of its center of gravity. Thus [7] will be at once the energy equation for the relative motion by merely interpreting the notations s_1, s_2, s_3, s_4, and v_1, v_2, v_3, v_4 to have reference thereto, and no separate system of coördinates is needed. Wherever in the following paragraphs these notations are used, it will be sufficient to mention whether they have reference to the absolute or to the relative motion.

35 The reader no doubt will have observed that the deductions of this article are true only when the external forces engaging the system are independent of the motion of the machine part on which they act. In other words, the external forces must either be constant or explicit functions of the time.

4 NORMAL COÖRDINATES AND CONSTANTS AND THEIR DETERMINATION

36 According to the theory of normal coördinates, each *relative* displacement will be the sum of a certain number of normal displacements, each normal displacement being the product of a normal constant into a normal coördinate. Thus, the relative displacements s_1, s_2, s_3, s_4 expressed in normal coördinates will appear in the form

$$\begin{aligned}
s_1 &= u_{1a}\phi_a + u_{1b}\phi_b + u_{1c}\phi_c + u_{1d}\phi_d + \ldots\ldots\ldots\ldots \\
s_2 &= u_{2a}\phi_a + u_{2b}\phi_b + u_{2c}\phi_c + u_{2d}\phi_d + \ldots\ldots\ldots\ldots \\
s_3 &= u_{3a}\phi_a + u_{3b}\phi_b + u_{3c}\phi_c + u_{3d}\phi_d + \ldots\ldots\ldots\ldots \\
s_4 &= u_{4a}\phi_a + u_{4b}\phi_b + u_{4c}\phi_c + u_{4d}\phi_d + \ldots\ldots\ldots\ldots
\end{aligned}$$

The *relative* displacement s_4, for instance, is the sum of the normal displacements $u_{4a}\phi_a$, $u_{4b}\phi_b$, $u_{4c}\phi_c$, etc., of which there will be as many as there are normal coördinates; u_{4a}, u_{4b}, u_{4c} being the normal constants and ϕ_a, ϕ_b, ϕ_c the normal coördinates. In the hydraulic machine, Fig. 1, we have the *relative* displacements s_1, s_2, s_3, and s_4. The number of normal coördinates, as the calculation will automatically show, is three, and therefore each *relative* displacement will be the sum of three normal displacements, whence

$$\left.\begin{aligned}
s_1 &= u_{1a}\phi_a + u_{1b}\phi_b + u_{1c}\phi_c \\
s_2 &= u_{2a}\phi_a + u_{2b}\phi_b + u_{2c}\phi_c \\
s_3 &= u_{3a}\phi_a + u_{3b}\phi_b + u_{3c}\phi_c \\
s_4 &= u_{4a}\phi_a + u_{4b}\phi_b + u_{4c}\phi_c
\end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots [11a]$$

37 The *absolute* displacements, as already stated, are the sums of the rigid and relative displacements. Thus, to obtain the *absolute*

displacements we merely have to add the corresponding rigid displacements to the right-hand members of Equations [11*a*], whence

$$\left.\begin{aligned} s_1 &= u_{1a}\phi_a + u_{1b}\phi_b + u_{1c}\phi_c + \sigma_1 \\ s_2 &= u_{2a}\phi_a + u_{2b}\phi_b + u_{2c}\phi_c + \sigma_2 \\ s_3 &= u_{3a}\phi_a + u_{3b}\phi_b + u_{3c}\phi_c + \sigma_3 \\ s_4 &= u_{4a}\phi_a + u_{4b}\phi_b + u_{4c}\phi_c + \sigma_4 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots [11b]$$

It will be noted that the notations here employed are such that in the equation for any given displacement the normal constants as well as the displacement carry the same numerical subscript. Thus, in the expression for the displacement s_4, all normal constants have the numerical subscript 4. While apparently the calculation of the *relative* displacements according to [11*a*] or of the *absolute* displacements according to [11*b*], requires the determination of 12 normal constants u and three normal coördinates ϕ, our labors will be considerably shortened by making use of some properties of normal coördinates.

38 One of these properties is that all normal constants having the same numerical subscript, e.g., the normal constants u_{4a}, u_{4b}, u_{4c}, are all functions of one and the same kind but of different parameters p_a, p_b, p_c. If, therefore, we succeed in determining the equation for a general normal constant u_4 as a function of a general parameter p, we shall at once be able to write down the expressions for the normal constants u_{4a}, u_{4b}, u_{4c} by substituting p_a, p_b, p_c, respectively, for p. The normal constants u_{4a}, u_{4b}, u_{4c}, then, will be the constants of the general type u_4 but corresponding to the parameters p_a, p_b, p_c, respectively.

39 The same applies to the other normal constants, and thus the object is to determine four general normal constants u_1, u_2, u_3, u_4, as a function of a general parameter p, such that substitution therein of p_a for p gives the normal constants u_{1a}, u_{2a}, u_{3a}, u_{4a}; of p_b for p, the normal constants u_{1b}, u_{2b}, u_{3b}, u_{4b}; and of p_c for p, the normal constants u_{1c}, u_{2c}, u_{3c}, u_{4c}.

40 Suppose for the moment that we have succeeded in determining the general normal constant u_4 as a function of the general parameter p, such that

$$u_4 = f(p) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [12a]$$

According to the above, then

$$u_{4a} = f(p_a); \quad u_{4b} = f(p_b); \quad u_{4c} = f(p_c) \ldots\ldots\ldots [12b]$$

Evidently, to derive Equations [12*b*] from [12*a*] we merely have added the subscripts a, b and c, respectively. Thus, the foregoing is

capable of the following much broader interpretation: If, namely, by definition the subscripts a, b, c, added to the general parameter p indicate the actual parameters of the system, any quantity or any equation between quantities referred to the general parameter p, will at once correspond to the parameters p_a, p_b, p_c by the addition thereto of the subscripts a, b, c, respectively.

41 The above also applies to the normal coördinates ϕ_a, ϕ_b, ϕ_c, which are functions of one and the same type of the time but of different parameters p_a, p_b, p_c. Thus again the object is to derive the equation for a single general normal coördinate ϕ as a function of the time and of quantities referred to the general parameter p, from which the actual normal coördinates of the system may be obtained in the simple manner explained above.

42 The *relative* velocities of the system are obtained by differentiation in respect to time of the Equations [**11***a*]. Since in the right-hand members thereof ϕ_a, ϕ_b, ϕ_c are the only functions of the time, we have

$$\left.\begin{aligned}
v_1 &= \frac{ds_1}{dt} = u_{1a}\frac{d\phi_a}{dt} + u_{1b}\frac{d\phi_b}{dt} + u_{1c}\frac{d\phi_c}{dt}\\
v_2 &= \frac{ds_2}{dt} = u_{2a}\frac{d\phi_a}{dt} + u_{2b}\frac{d\phi_b}{dt} + u_{2c}\frac{d\phi_c}{dt}\\
v_3 &= \frac{ds_3}{dt} = u_{3a}\frac{d\phi_a}{dt} + u_{3b}\frac{d\phi_b}{dt} + u_{3c}\frac{d\phi_c}{dt}\\
v_4 &= \frac{ds_4}{dt} = u_{4a}\frac{d\phi_a}{dt} + u_{4b}\frac{d\phi_b}{dt} + u_{4c}\frac{d\phi_c}{dt}
\end{aligned}\right\}\cdots\cdots\cdots\cdots[\mathbf{13}a]$$

43 The *absolute* velocities are obtained by adding the rigid velocities to the right-hand members of [**13***a*], whence

$$\left.\begin{aligned}
v_1 &= u_{1a}\frac{d\phi_a}{dt} + u_{1b}\frac{d\phi_b}{dt} + u_{1c}\frac{d\phi_c}{dt} + v_1\\
v_2 &= u_{2a}\frac{d\phi_a}{dt} + u_{2b}\frac{d\phi_b}{dt} + u_{2c}\frac{d\phi_c}{dt} + v_2\\
v_3 &= u_{3a}\frac{d\phi_a}{dt} + u_{3b}\frac{d\phi_b}{dt} + u_{3c}\frac{d\phi_c}{dt} + v_3\\
v_4 &= u_{4a}\frac{d\phi_a}{dt} + u_{4b}\frac{d\phi_b}{dt} + u_{4c}\frac{d\phi_c}{dt} + v_4
\end{aligned}\right\}\cdots\cdots\cdots\cdots[\mathbf{13}b]$$

44 To obtain the expressions for the general normal constants u_1, u_2, u_3, u_4, and for the general normal coördinate ϕ, we apply another property of normal coördinates, according to which the general energy equation of the *relative* motion is satisfied when replacing therein

quantities referred to Cartesian coördinates by the corresponding quantity pertaining to any one of the normal coördinates.

45 Thus, Equation [7], which, as we have seen, is also the energy equation for the relative motion must be satisfied when replacing therein the relative *Cartesian displacements* s_1, s_2, s_3, s_4, by the general *normal displacements* $u_1\phi, u_2\phi, u_3\phi, u_4\phi$. Placing therefore

$$s_1 = u_1\phi, \quad s_2 = u_2\phi, \quad s_3 = u_3\phi, \quad s_4 = u_4\phi \ldots\ldots\ldots [13c]$$

from which by differentiation in respect to time we derive

$$v_1 = u_1\frac{d\phi}{dt}, \quad v_2 = u_2\frac{d\phi}{dt}, \quad v_3 = u_3\frac{d\phi}{dt}, \quad v_4 = u_4\frac{d\phi}{dt} \ldots [13d]$$

and substituting in [7], we obtain

$$\begin{aligned}&\{u_1^2m_1 + u_2^2m_2 + u_3^2m_3 + u_4^2(m_3' + m_4)\}\left(\frac{d\phi}{dt}\right)^2 - 2T_0\\ &+ \left\{\frac{(u_2 - u_1)^2}{a_1} + \frac{(u_3 + u_4 - u_2)^2}{a_2} + \frac{(u_4 - u_3)^2}{a_3}\right\}\phi^2 - 2V_0\\ &= 2\int_0^t \{u_4P - u_2F_2 - u_3F_3 - g(u_1m_1 - u_4m_3' - u_4m_4)\}\frac{d\phi}{dt}dt\end{aligned}$$

46 To integrate this equation, we first differentiate in respect to time. The constants T_0 and V_0 vanish and we have

$$\left.\begin{aligned}&2\{u_1^2m_1 + u_2^2m_2 + u_3^2m_3 + u_4^2(m_3' + m_4)\}\frac{d^2\phi}{dt^2}\frac{d\phi}{dt}\\ &+ 2\left\{\frac{(u_2 - u_1)^2}{a_1} + \frac{(u_3 + u_4 - u_2)^2}{a_2} + \frac{(u_4 - u_3)^2}{a_3}\right\}\phi\frac{d\phi}{dt}\\ &= 2\{u_4P - u_2F_2 - u_3F_3 - g(u_1m_1 - u_4m_3' - u_4m_4)\}\frac{d\phi}{dt}\end{aligned}\right\} \ldots [14]$$

We divide both members of the above equation by $2\,d\phi/dt$ and place

$$u_1^2m_1 + u_2^2m_2 + u_3^2m_2 + u_4^2(m_3' + m_4) = \alpha \ldots\ldots [15a]$$

$$\frac{(u_2 - u_1)^2}{a_1} + \frac{(u_3 + u_4 - u_2)^2}{a_2} + \frac{(u_4 - u_3)^2}{a_3} = \beta \ldots\ldots [15b]$$

$$\frac{\beta}{\alpha} = p^2 = \frac{\dfrac{(u_2 - u_1)^2}{a_1} + \dfrac{(u_3 + u_4 - u_2)^2}{a_2} + \dfrac{(u_4 - u_3)^2}{a_3}}{u_1^2m_1 + u_2^2m_2 + u_3^2m_3 + u_4^2(m_3' + m_4)} \ldots [15c]$$

$$u_4P - u_2F_2 - u_3F_3 - g(u_1m_1 - u_4m_3' - u_4m_4) = Q \ldots [15d]$$

whence, by substitution in [14] we obtain

$$\frac{d^2\phi}{dt^2} + p^2\phi = \frac{Q}{\alpha} \ldots\ldots\ldots\ldots\ldots\ldots [16]$$

47 The expressions for the general normal constants as a function of the general parameter p are determined from certain relations which

exist amongst them. These relations, the writer found, can be obtained from [15c] by the simple process of differentiation. Writing [15c] in the form

$$p^2\{u_1^2m_1 + u_2^2m_2 + u_3^2m_3 + v_4^2(m_3' + m_4)\} = \frac{(u_2 - u_1)^2}{a_1} + \frac{(u_3 + u_4 - u_2)^2}{a_2} + \frac{(u_4 - u_3)^2}{a_3}$$

the above relations are found by successively taking the partial derivatives in respect to u_1, u_2, u_3, u_4. This gives

$$p^2u_1m_1 = -\frac{u_2 - u_1}{a_1} \quad \text{[17a]}$$

$$p^2u_2m_2 = \frac{u_2 - u_1}{a_1} - \frac{u_3 + u_4 - u_2}{a_2} \quad \text{[17b]}$$

$$p^2u_3m_3 = \frac{u_3 + u_4 - u_2}{a_2} - \frac{u_4 - u_3}{a_3} \quad \text{[17c]}$$

$$p^2u_4(m_3' + m_4) = \frac{u_3 + u_4 - u_2}{a_2} + \frac{u_4 - u_3}{a_3} \quad \text{[17d]}$$

48 Instead of operating directly with these equations, it is always possible and time-saving to slightly modify some of them. In the present case we shall derive from them a new set of equations in the manner indicated below:

$$p^2u_1m_1 = -\frac{u_2 - u_1}{a_1} \quad \text{[18a], same as [17a]}$$

$$p^2(u_2m_2 + u_3m_3) = \frac{u_2 - u_1}{a_1} - \frac{u_4 - u_3}{a_3} \quad \text{[18b], by adding [17b] and [17c]}$$

$$-p^2\{u_3m_3 - u_4(m_3' + m_4)\} = 2\frac{u_4 - u_3}{a_3} \quad \text{[18c], subtracting [17c] from [17d]}$$

$$p^2u_4(m_3' + m_4) = \frac{u_3 + u_4 - u_2}{a_2} + \frac{u_4 - u_3}{a_3} \quad \text{[18d], same as [17d]}$$

49 Apparently we have here four algebraic equations between the five unknowns u_1, u_2, u_3, u_4, and p^2. Dividing, however, each of these equations by u_1, for instance, it will be seen that in reality we have four equations between p^2 and the proportions u_2/u_1, u_3/u_1, u_4/u_1. Since clearly it is possible only to determine the proportions of three of the general normal constants to a fourth one, we conclude that one of them is arbitrary and may be placed equal to unity. Placing in Equations [18] $u_1 = 1$ and rearranging, we have

$$\frac{u_2}{a_1} = -p^2m_1 + \frac{1}{a_1} \quad \text{[19a]}$$

$$\left(\frac{1}{a_1} - p^2m_2\right)u_2 - \left(p^2m_3 - \frac{1}{a_3}\right)u_3 = \frac{1}{a_1} \quad \text{[19b]}$$

$$\left(p^2m_3 - \frac{2}{a_3}\right)u_3 - \left\{p^2(m_3' + m_4) - \frac{2}{a_3}\right\}u_4 = 0 \ldots\ldots [19c]$$

$$-\frac{u_2}{a_2} + \left(\frac{1}{a_2} - \frac{1}{a_3}\right)u_3 - \left\{p^2(m_3' + m_4) - \frac{1}{a_2} - \frac{1}{a_3}\right\}u_4 = 0 \ldots [19d]$$

Considering in [19*a*], [19*b*] and [19*c*] the general normal constants u_2, u_3, u_4 as the unknowns and solving, we obtain

$$u_4 = \frac{\left(\frac{2}{a_3} - p^2m_3\right)\left\{\frac{1}{a_1}(m_1 + m_2) - p^2m_1m_2\right\}}{\frac{1}{a_1}\left\{-\frac{1}{a_3}(m_3 + m_3' + m_4) + p^2m_3(m_3' + m_4)\right\}} \ldots\ldots [20a]$$

$$u_3 = \frac{\left\{\frac{2}{a_3} - p^2(m_3' + m_4)\right\}\left\{\frac{1}{a_1}(m_1 + m_2) - p^2m_1m_2\right\}}{\frac{1}{a_1}\left\{-\frac{1}{a_3}(m_3 + m_3' + m_1) + p^2m_3(m_3' + m_4)\right\}} \ldots [20b]$$

$$u_2 = 1 - a_1p^2m_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [20c]$$

Further, as already mentioned,

$$u_1 = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [20d]$$

50 Substituting for u_2, u_3, u_4 from Equations [20] in [19*d*], we obtain

$$\begin{aligned} & m_1m_2m_3(m_3' + m_4)\,p^6 \\ & - \left\{\left(\frac{1}{a_2} + \frac{1}{a_3}\right)m_1m_2(m_3 + m_3' + m_4) + \frac{1}{a_1}m_3(m_3' + m_4)(m_1 + m_2)\right. \\ & \left. + \frac{1}{a_2}m_1m_3(m_3' + m_4)\right\}p^4 + \left\{\frac{1}{a_2a_3}m_1(4m_2 + m_3 + m_3' + m_4)\right. \\ & \left. + \frac{1}{a_1}\left(\frac{1}{a_2} + \frac{1}{a_3}\right)(m_1 + m_2)(m_3 + m_3' + m_4) + \frac{1}{a_1a_2}m_3(m_3' + m_4)\right\}p^2 \\ & - \frac{1}{a_1a_2a_3}(4m_1 + 4m_2 + m_3 + m_3' + m_4) = 0 \ldots\ldots\ldots\ldots [21] \end{aligned}$$

This is the so-called characteristic equation of the system here under consideration. The name is derived from the fact that each of the positive roots of this equation will be a parameter of the system. In the present case [21] is of the third degree in respect to p^2. The coefficients being alternately positive and negative (as is always the case), the three roots p^2 will all be positive. There consequently will be three positive roots p, which are designated, beginning with the smallest, by p_a, p_b, p_c, and these are the parameters of the system with

which we here are concerned. Since there is a normal coördinate to each parameter, the number of positive roots of the characteristic equation automatically indicates the number of normal coördinates. As a rule there will be as many as there are parts in the machine considered to be elastic.

51 An examination of Equations [20] and [21] will show that the numerical values of the normal constants and of the parameters of the system depend not only on the inertia of the rigid parts and on the elasticity of the elastic parts of the machine, but also on their position in the system. That is to say, other values occur when, for instance, exchanging m_1 and m_3 or a_1 and a_3.

52 From Equations [18] another interesting equation may be derived, which is also useful as a check on the calculation of the normal constants. Adding [18*a*], [18*b*] and [18*c*] after first multiplying the two first named by 2, we obtain

$$2\,u_1m_1 + 2\,u_2m_2 + u_3m_3 + u_4\,(m_3' + m_4) = 0 \ldots\ldots [22a]$$

The interpretation of this equation becomes clear upon multiplying its members by ϕ, whence

$$2\,u_1m_1\phi + 2\,u_2m_2\phi + u_3m_3\phi + u_4\,(m_3' + m_4)\,\phi = 0$$

and from which on account of Equations [13*c*], we derive

$$2\,m_1\,s_1 + 2\,m_2\,s_2 + m_3\,s_3 + (m_3' + m_4)\,s_4 = 0 \ldots\ldots [22b]$$

53 In this equation s_1, s_2, s_3, s_4 are of course relative displacements, and it expresses the fact that in the relative motion of the machine the center of gravity is not disturbed.

54 The next object to engage our attention consists in the determination of the general normal coördinate ϕ. This follows at once by integrating [16], of which the general solution is

$$\phi = \left(\frac{d\phi}{dt}\right)_0 \frac{\sin pt}{p} + (\phi)_0 \cos pt$$
$$+ \frac{1}{\alpha p}\left\{\sin pt \int_0^t Q \cos pt\,dt - \cos pt \int_0^t Q \sin pt\,dt\right\} \ldots [23]$$

This is the general equation for the general normal coördinate for any machine. Therein $(d\phi/dt)_0$ and $(\phi)_0$ denote the values of $d\phi/dt$ and ϕ at the time $t = 0$. These are constants of the integration, the former depending on the initial velocities and the latter on the initial displacements of the machine parts. They are expressed as follows:

$$\left(\frac{d\phi}{dt}\right)_0 = \frac{1}{\alpha}\{m_1u_1(v_1)_0 + m_2u_2(v_2)_0 + m_3u_3(v_3)_0 + (m_3' + m_4)\,u_4(v_4)_0\}\,.\,[24a]$$

$$(\phi)_0 = \frac{1}{\alpha}\{m_1u_1(s_1)_0 + m_2u_2(s_2)_0 + m_3u_3(s_3)_0 + (m_3' + m_4)\,u_4(s_4)_0\}\,..\,[24b]$$

55 In the above it is immaterial whether $(s_1)_0$, $(s_2)_0$, $(s_3)_0$, etc., and $(v_1)_0$, $(v_2)_0$, $(v_3)_0$, etc., are absolute or relative displacements and velocities. In connection with problems of engineering it is simpler, however, to express $(\phi)_0$ in function of the forces $(S_1)_0$, $(S_2)_0$, $(S_3)_0$, with which at the time $t = 0$ the elastic machine members (here the ropes *ab*, *cd*, *ef*) react on the rigid machine parts which they connect. According to the writer's investigation it was found that

$$(\phi)_0 = \frac{1}{\alpha p^2}\{(u_2 - u_1)(S_1)_0 + (u_3 + u_4 - u_2)(S_2)_0 + (u_4 - u_3)(S_3)_0\}\,..\,[24c]$$

56 In Equations [24*a*], [24*b*] and [24*c*] the expressions between parentheses apply only to the hydraulic machine, Fig. 1. They are, however, always easy to write down for any other machine. For, having derived for that machine the equations [15*a*], the expression between parentheses of [24*a*] can be obtained therefrom by multiplying the first term by $(v_1)_0/u_1$, the second term by $(v_2)_0/u_2$, the third term by $(v_3)_0/u_3$, etc. Similarly, the expression between parentheses of [24*c*] can be obtained from [15*b*] by employing the first powers of each of its terms, after which the first is multiplied by $a_1\,(S_1)_0$, the second by $a_2\,(S_2)_0$, the third by $a_3\,(S_3)_0$, etc. The mathematical derivation of Equations [24*a*], [24*b*] and [24*c*] is omitted, as it would require a more detailed exposition of the theory of normal coördinates than for which there is opportunity here.

57 Returning to Equation [23], it will be seen that the determination of ϕ depends on our ability to solve two definite integrals, which in turn requires the knowledge of the quantity Q as a function of the time. Q, however (see [15*d*]), is a function of the external forces acting on the machine, of which in general all except the motive force P are constant or practically so. Thus it is clear that we cannot determine ϕ unless that we know the motive force as a function of the time.

58 This, however, is only possible with existing machines, where a graph showing for each instant the corresponding value of the motive force may be obtained experimentally. Evidently such a graph is all that is required. For, from this we can derive a graph of Q relative to time, with which in turn we can lay out two curves

with times as abscissæ and the corresponding values of $Q \sin pt$ and $Q \cos pt$, respectively, as ordinates. The definite integrals $\int_0^t Q \sin pt\, dt$ and $\int_0^t Q \cos pt\, dt$ in [23] then represent areas of the above curves comprised between the ordinates for $t = t$ and $t = 0$, which can be obtained by use of a planimeter. Thus in existing machines it is possible accurately to determine the normal coördinates of the system and to derive from them accurately the values of the internal forces S_1, S_2, and S_3.

59 In the majority of cases the problem concerns machines yet to be built, and while it becomes necessary to resort to approximation methods, they can be made as close as the calculator desires. The method here referred to will be explained in detail in Part 5. It is at present sufficient to remark that we always can select time intervals so small that no material error will be made by assuming the motive force to be constant during such periods. Thus we are only interested in deriving the expression for the general normal coördinate for a constant motive force. Referring to [15*d*], it will be seen that with P constant, Q also becomes a constant, whence by executing the integrations in [23] the result can be written in the following form:

$$\phi = \frac{1}{p}\left[\frac{Q}{\alpha p} + \left(\frac{d\phi}{dt}\right)_0 \sin pt + \left\{(\phi)_0 p - \frac{Q}{\alpha p}\right\} \cos pt\right] \ldots . [25a]$$

60 In our future calculations we shall also have need of the expression for $d\phi/dt$, which may be obtained by differentiating [25*a*] in respect to time, whence:

$$\frac{d\phi}{dt} = \left(\frac{d\phi}{dt}\right)_0 \cos pt - \left\{(\phi_0)\, p - \frac{Q}{\alpha p}\right\} \sin pt \ldots\ldots\ldots [25b]$$

To derive from [25*a*] and [25*b*] the expressions for the normal coördinate ϕ_a and its derivative $d\phi_a/dt$, we shall merely have to attach the subscript a to all quantities corresponding to the general parameter p. These, according to [15*a*], [15*b*], [24*a*] and [24*c*] are the quantities α, Q, $(d\phi/dt)_0$ and $(\phi)_0$. Hence we have

$$\phi_a = \frac{1}{p_a}\left[\frac{Q_a}{\alpha_a p_a} + \left(\frac{d\phi_a}{dt}\right)_0 \sin p_a t + \left\{(\phi_a)_0 p_a - \frac{Q_a}{\alpha_a p_a}\right\} \cos p_a t\right] .. [26a]$$

$$\frac{d\phi_a}{dt} = \left(\frac{d\phi_a}{dt}\right)_0 \cos p_a t - \left\{(\phi_a)_0 p_a - \frac{Q_a}{\alpha_a p_a}\right\} \sin p_a t \ldots\ldots\ldots\ldots [26b]$$

wherein, by application of the same process to [15a], [15b], [24a] and [24c],

$$\alpha_a = u_{1a}^2 m_1 + u_{2a}^2 m_2 + u_{3a}^2 m_3 + u_{4a}^2 (m_3' + m_4) \ldots\ldots\ldots\ldots [26c]$$

$$Q_a = u_{4a} P - u_{2a} F_2 - u_{3a} F_3 - g \{ u_{1a} m_1 - u_{4a} (m_3' + m_4) \} \ldots [26d]$$

$$\left(\frac{d\phi_a}{dt}\right)_0 = \frac{1}{\alpha_a} \{ m_1 u_{1a} (v_1)_0 + m_2 u_{2a} (v_2)_0 + m_3 u_{3a} (v_3)_0 + (m_3' + m_4) u_{4a} (v_4)_0 \} \ldots\ldots\ldots\ldots [26e]$$

$$(\phi_a)_0 = \frac{1}{\alpha_a p_a^2} \{ (u_{2a} - u_{1a}) (S_1)_0 + (u_{3a} + u_{4a} - u_{2a}) (S_2)_0 + (u_{4a} - u_{3a}) (S_3)_0 \} \ldots\ldots\ldots\ldots [26f]$$

61 In the same manner we find for the normal coördinate ϕ_b and its derivative $d\phi_b/dt$:

$$\phi_b = \frac{1}{p_b} \left[\frac{Q_b}{\alpha_b p_b} + \left(\frac{d\phi_b}{dt}\right)_0 \sin p_b t + \left\{ (\phi_b)_0 p_b - \frac{Q_b}{\alpha_b p_b} \right\} \cos p_b t \right] \ldots [27a]$$

$$\frac{d\phi_b}{dt} = \left(\frac{d\phi_b}{dt}\right)_0 \cos p_b t - \left\{ (\phi_b)_0 p_b - \frac{Q_b}{\alpha_b p_b} \right\} \sin p_b t \ldots\ldots\ldots\ldots [27b]$$

$$\alpha_b = u_{1b}^2 m_1 + u_{2b}^2 m_2 + u_{3b}^2 m_3 + u_{4b}^2 (m_3' + m_4) \ldots\ldots\ldots [27c]$$

$$Q_b = u_{4b} P - u_{2b} F_2 - u_{3b} F_3 - g \{ u_{1b} m_1 - u_{4b} (m_3' + m_4) \} \ldots [27d]$$

$$\left(\frac{d\phi_b}{dt}\right)_0 = \frac{1}{\alpha_b} \{ m_1 u_{1b} (v_1)_0 + m_2 u_{2b} (v_2)_0 + m_3 u_{3b} (v_3)_0 + (m_3' + m_4) u_{4b} (v_4)_0 \} \ldots\ldots\ldots\ldots [27e]$$

$$(\phi_b)_0 = \frac{1}{\alpha_b p_b^2} \{ (u_{2b} - u_{1b}) (S_1)_0 + (u_{3b} + u_{4b} - u_{2b}) (S_2)_0 + (u_{4b} - u_{3b}) (S_3)_0 \} \ldots\ldots\ldots\ldots [27f]$$

62 Similarly we can derive the expressions for the normal coordinate ϕ_c. The same is, however, exceedingly small and may be neglected. As a matter of fact, in all calculations of the kind with which we here are concerned it is more than sufficient for practical purposes to operate with the two normal coördinates only, corresponding to the two lower roots of the characteristic equation [21].

63 An inspection of [26a] and [27a] will show that the angular functions therein indicate that we have to deal with vibrations of different frequencies. In the present case (see [11a]) a relative displacement will be the sum of the products of three normal coordinates into a constant. Thus each relative displacement will be the superposition of three vibrations with frequencies corresponding to the three parameters of the system p_a, p_b, p_c. Denoting the frequencies by f_a, f_b, f_c, in cycles per second, we evidently have

$$f_a = \frac{p_a}{2\pi}; \quad f_b = \frac{p_b}{2\pi}; \quad f_c = \frac{P_c}{2\pi}$$

The neglecting of the coördinate ϕ_c is equivalent to the omission of the vibrations corresponding to the parameter p_c, i.e., the vibration of the highest frequency. This is justified, not only because of the very small numerical value of ϕ_c, but also on account of the fact that vibrations of high frequency very soon vanish by damping.

5 NUMERICAL EXAMPLE

64 The data for the hydraulic machine, Fig. 1, are as follows:

m_1g = weight of load A = 58,000 lb.
m_1 = mass of load A = 58,000/32.16 = 1,800
m_2 = mass of sheave B reduced to radius O_2b = 170
$m_2'g$ = weight of sheave C = 5,400 lb.
m_2' = mass of sheave C = 168
m_3 = mass of sheave C reduced to radius O_3d = 80
m_4g = weight of piston plus piston rod = 9,075 lb.
m_4 = mass of piston and piston rod = 282

At the time t = 0, the free length of each of the ropes ab, cd, and ef was 67 ft., 0 in., each consisting of four 1⅛-in. single steel ropes, whence

$a_1 = a_2 = a_3$ = elongation for a load of 1 lb. = 1/300,000 ft.
F_2 = friction of sheave B measured at radius O_2b = 3,000 lb.
F_3 = friction of sheave C measured at radius O_3d = 3,300 lb.

The frictions — as already agreed upon — will be considered constant for the entire duration of the start and acting in the direction shown in Fig. 1, whence

$(S_1)_0$ = force at time t = 0 with which rope ab reacts on load A and sheave B = 58,000 lb.
$(S_2)_0$ = force at time t = 0 with which rope cd reacts on sheaves B and C = 58,000 + F_2 = 61,000 lb.
$(S_3)_0$ = force at time t = 0 with which rope ef reacts on sheave C and the hitch at f = 61,000 + F_3 = 64,300 lb.

65 All calculations will be made by slide rule. Substituting for $m_1, m_2, \ldots, a_1, a_2, a_3$, in the characteristic equation [21], we obtain:

$$p^6 - 1.255 \times 10^4 p^4 + 3.52 \times 10^7 p^2 - 2.064 \times 10^{10} = 0$$

This equation is solved for p^2 by one of the known methods for the solution of cubic equations or by trial, whence the three roots will be

$$p_a^2 = 800; \quad p_b^2 = 2{,}920; \quad p_c^2 = 8{,}830$$

As the parameters p_a, p_b, p_c are the positive roots of the above, we have

$$p_a = 28.28; \quad p_b = 54; \quad p_c = 94$$

Substituting for a_1, a_2, a_3, m_1, m_2, etc., in Equations [20], we obtain for the general normal constants:

$$u_4 = \frac{(6 \times 10^5 - 80\,p^2)(5.91 \times 10^8 - 3.06 \times 10^5 p^2)}{3 \times 10^5(-1.59 \times 10^8 + 3.6 \times 10^4 p^2)} \quad \ldots [28a]$$

$$u_3 = \frac{(6 \times 10^5 - 450\,p^2)\,(5.91 \times 10^8 - 3.06 \times 10^5\,p^2)}{3 \times 10^5\,(-1.59 \times 10^8 + 3.6 \times 10^4\,p^2)} \quad \ldots [28b]$$

$$u_2 = 1 - 6 \times 10^{-3}\,p^2 \ldots\ldots [28c]$$

$$u_1 = 1 \ldots\ldots [28d]$$

66 The normal constants u_{4a}, u_{3a}, u_{2a}, u_{1a}, corresponding to the parameter p_a — as already previously explained — are derived from the above in the manner indicated below:

$$\left.\begin{array}{l} u_{4a} \text{ from } [28a] \\ u_{3a} \text{ from } [28b] \\ u_{2a} \text{ from } [28c] \\ u_{1a} \text{ from } [28d] \end{array}\right\} \begin{array}{l} \text{by substituting} \\ \quad p_a = 28.28 \text{ for } p, \text{ whence} \end{array} \left\{\begin{array}{l} u_{4a} = -4.83 \\ u_{3a} = -2.12 \\ u_{2a} = -3.8 \\ u_{1a} = +1 \end{array}\right.$$

and similarly,

$$\left.\begin{array}{l} u_{4b} \text{ from } [28a] \\ u_{3b} \text{ from } [28b] \\ u_{2b} \text{ from } [28c] \\ u_{1b} \text{ from } [28d] \end{array}\right\} \begin{array}{l} \text{by substituting} \\ \quad p_b = 54 \text{ for } p, \text{ whence} \end{array} \left\{\begin{array}{l} u_{4b} = +6.85 \\ u_{3b} = -13.33 \\ u_{2b} = -16.52 \\ u_{1b} = +1 \end{array}\right.$$

Owing to the neglecting of the coördinate ϕ_c, the calculation of the normal constants u_{1c}, u_{2c}, u_{3c}, u_{4c}, will not be required.

67 For a check on the above calculations we employ [22a]. This equation corresponds in the same form to the normal constants corresponding to the parameters p_a and p_b, and according to the foregoing we will have

$$2\,u_{1a}m_1 + 2\,u_{2a}m_2 + u_{3a}m_3 + u_{4a}\,(m_3' + m_4) = 0$$

$$2\,u_{1b}m_1 + 2\,u_{2b}m_2 + u_{3b}m_3 + u_{4b}\,(m_3' + m_4) = 0$$

68 With the numerical values of the several normal constants known, we derive from [26c], [26d], [27c] and [27d]:

$$\left.\begin{array}{l} \alpha_a = +15{,}100 \\ Q_a = -4.83\,P - 109{,}400 \end{array}\right\} [30a]; \quad \left.\begin{array}{l} \alpha_b = +83{,}500 \\ Q_b = +6.85\,P + 133{,}200 \end{array}\right\} \ldots [30b]$$

We are now ready to determine the normal coördinates ϕ_a and ϕ_b, and shall make use thereby of the so-called motor characteristics. In order not to confine ourselves to the hydraulic machine, Fig. 1, we shall in general define the motor to be that machine part which is the seat of the motive force, irrespective of whether the latter is due to hydraulic, electric or steam pressure. As is known, the force or torque exerted by these motors varies with the motor speed, although the manner in which these variations take place is generally too complex to be adequately expressed in a mathematical formula.

Fortunately the latter is not necessary for our purposes, since it is always possible from test data to derive a graph showing the variation of the motive force with the motor speed. In particular, with some types of electric motors such a graph is easily obtainable from shop tests with the motor alone.

69 In the present case the motor characteristics will be the performance of the piston alone when operating in the cylinder under the given conditions as to size of piping, operating valve, and water-pressure delivered by the pumps. It is represented in Fig. 2 and shows the net force P which the piston rod is capable of exerting at various piston speeds. In the complete machine the graph Fig. 2 will of course represent the relation between the *absolute* piston speed and the motive force P.

70 Obviously we can always divide the starting period in intervals of so small duration that during such intervals the motive force may be considered to be constant, without committing an appreciable error.

71 In explanation of the process now to be followed, our main object of course is the determination of S_1, S_2, S_3, which, according to [3*a*], [3*b*] and [3*c*], requires the knowledge of the *relative* displacements s_1, s_2, s_3, s_4. As has been shown in Part 3, relative and absolute displacements are interchangeable in the above-mentioned equations. The relative displacements are expressed by [11*a*], and equating therein ϕ_e to zero, we obtain

$$\left.\begin{aligned} s_1 &= u_{1a}\phi_a + u_{1b}\phi_b \\ s_2 &= u_{2a}\phi_a + u_{2b}\phi_b \\ s_3 &= u_{3a}\phi_a + u_{3b}\phi_b \\ s_4 &= u_{4a}\phi_a + u_{4b}\phi_b \end{aligned}\right\} \qquad [31]$$

Since we already know the numerical values of the various normal constants in the above, our immediate requirements consist in the determination of the normal coördinates ϕ_a and ϕ_b, which requires the knowledge of the magnitude of the motive force for each individual time interval in which the start is to be subdivided. Evidently for this purpose we have to determine the *absolute* piston speed v_4 at the beginning of each time interval, whence the corresponding motive force can at once be ascertained from the motor characteristics, Fig. 2. According to the fourth of Equations [13*b*], equating therein $d\phi_e/dt = 0$, the former is expressed by

$$v_4 = u_{4a}\frac{d\phi_a}{dt} + u_{4b}\frac{d\phi_b}{dt} + v_4 \qquad [32]$$

and requires the determination of the values of $d\phi_a/dt$, $d\phi_b/dt$, and of the rigid piston speed v_4. In order to obtain the latter, we differentiate [10] in respect to time, whence

$$\frac{dv_4}{dt} = \frac{P - 2F_2 - F_3 - g(2m_1 - m_3' - m_4)}{4(m_1 + m_2) + m_3 + m_3' + m_4} = \frac{P - 111{,}000}{8{,}400}.$$

Integrating, we have, since P is constant for each individual time interval,

$$v_4 = (v_4)_0 + \left(\frac{P - 111{,}000}{8{,}400}\right)t \ldots\ldots\ldots\ldots\ldots [33]$$

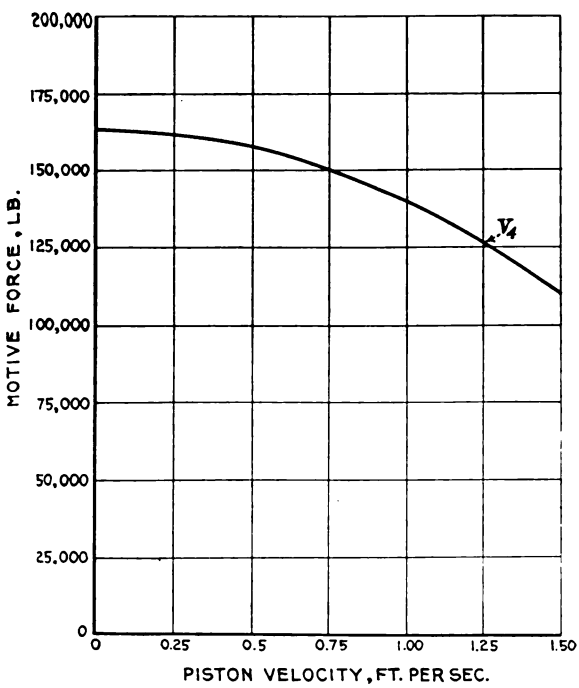

FIG. 2 MOTOR CHARACTERISTICS (MOTIVE FORCE AND PISTON VELOCITY)

wherein $(v_4)_0$ is the initial rigid piston speed. Applying now the foregoing, the manner of procedure will be as follows:

72 *First Time Interval.* The initial conditions are as follows: The initial velocities $(v_1)_0$, $(v_2)_0$, $(v_3)_0$, $(v_4)_0$ are zero, since the machine starts from rest, whence we find from [26*e*] and [27*e*]

$$\left(\frac{d\phi_a}{dt}\right)_0 = 0 \quad \text{and} \quad \left(\frac{d\phi_b}{dt}\right)_0 = 0$$

The initial tensions (see data under Par. 64) in the ropes *ab*, *cd* and

ef are: $(S_1)_0 = 58{,}000$; $(S_2)_0 = 61{,}000$; $(S_3)_0 = 64{,}300$; whence, by [26*f*] and [27*f*],

$$(\phi_a)_0 = -0.0533 \quad \text{and} \quad (\phi_b)_0 = +0.00367$$

These are the values of the normal coördinates ϕ_a and ϕ_b at the time $t = 0$. In Figs. 1, 3 and 4 they are laid off as ordinates against times as abscissæ.

73 In addition we obtain for zero piston speed from Fig. 2, $P =$ 163,000 lb., which will be constant for the duration of this time interval. Applying further [30*a*] and [30*b*], we have

$$Q_a = -8.97 \times 10^5, \quad \text{whence} \quad \frac{Q_a}{\alpha_a p_a} = -2.1$$

$$Q_b = +1.249 \times 10^6, \quad \text{whence} \quad \frac{Q_b}{\alpha_b p_b} = +0.23.$$

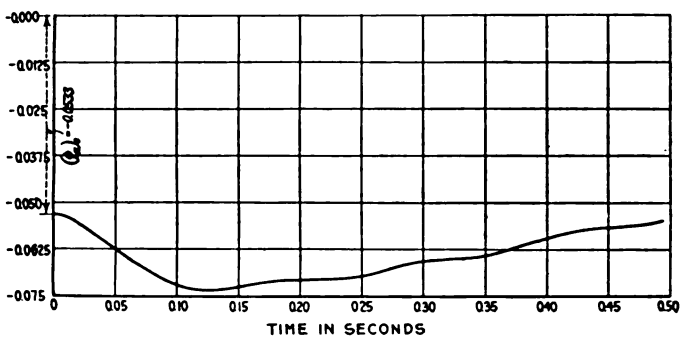

FIG. 3 NORMAL COÖRDINATE ϕ_a

74 Finally, applying [26*a*], [26*b*], [27*a*] and [27*b*], we obtain

$$\phi_a = \frac{-2.1 + (-0.0533 \times 28.28 + 2.1) \cos 28.28\, t}{28.28}$$

$$\frac{d\phi_a}{dt} = -(-0.0533 \times 28.28 + 2.1) \sin 28.28\, t$$

$$\phi_b = \frac{+0.23 + (+0.00367 \times 54 - 0.23) \cos 54\, t}{54}$$

$$\frac{d\phi_b}{dt} = -(+0.00367 \times 54 - 0.23) \sin 54\, t.$$

75 Taking the duration of the first time interval at $t = 0.005$ seconds, we have

$$28.28\, t = 28.28 \times 0.005 \text{ radian} = \frac{28.28 \times 0.005 \times 180^\circ}{\pi} = 8^\circ 6'$$

$$54\, t = 54 \times 0.005 \text{ radian} = \frac{54 \times 0.005 \times 180^\circ}{\pi} = 15^\circ 30',$$

whence

$$\sin 28.28\,t = 0.141; \quad \cos 28.28\,t = 0.99$$
$$\sin 54\,t = 0.267; \quad \cos 54\,t = 0.964$$

Substituting in the above, we obtain for the end of the first time interval:

$$\phi_a = -0.0535; \quad \frac{d\phi_a}{dt} = -0.0835; \quad \phi_b = 0.00372; \quad \frac{d\phi_b}{dt} = 0.021$$

For $P = 163{,}000$, $(v)_0 = 0$ and $t = 0.005$, we obtain from [33] for the rigid piston speed at the end of the first time interval: $v_4 = 0.031$ ft. per sec., whence by [32] the absolute piston speed will be

$$v_4 = 4.83 \times 0.0835 + 6.85 \times 0.021 + 0.031 = 0.578 \text{ ft. per sec.}$$

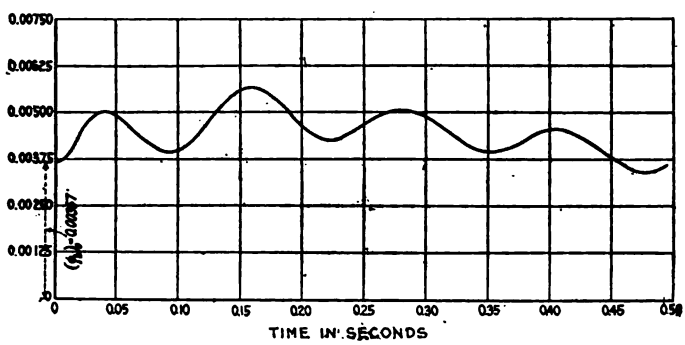

FIG. 4 NORMAL COÖRDINATE ϕ_b

The values of ϕ_a, ϕ_b, and v_4 at the end of the first time interval are laid off in Figs. 3, 4 and 9, respectively.

76 *Second Time Interval.* Evidently the values of ϕ_a, $d\phi_0/dt$, ϕ_b, $d\phi_b/dt$, v_4, and v_4 at the end of the first time interval are the initial values for the second. Thus the initial conditions are

$$(\phi_a)_0 = -0.0535; \quad \left(\frac{d\phi_a}{dt}\right)_0 = -0.0835; \quad (\phi_b)_0 = 0.00372; \quad \left(\frac{d\phi_b}{dt}\right)_0 = 0.021$$
$$(v_4)_0 = 0.031. \quad (v_4)_0 = 0.578.$$

The motive force corresponding to an *absolute* piston speed $v_4 = 0.578$ ft. per sec., according to Fig. 2, is $P = 155{,}200$ lb., which will be assumed to be constant for the duration of the second time interval. Applying [30*a*] and [30*b*], we have

$$Q_a = -8.58 \times 10^5, \quad \text{whence} \quad \frac{Q_a}{\alpha_a p_a} = -2.01$$
$$Q_b = 1.196 \times 10^6, \quad \text{whence} \quad \frac{Q_b'}{\alpha_b p_b} = 0.257$$

77 Now employing [26a], [26b], [27a] and [27b], we have

$$\phi_a = \frac{-2.01 - 0.0835 \sin 28.28\,t + (-0.0535 \times 28.28 + 2.01) \cos 28.28\,t}{28.28}$$

$$\frac{d\phi_a}{dt} = -0.0835 \cos 28.28\,t - (-0.0535 \times 28.28 + 2.01) \sin 28.28\,t$$

$$\phi_b = \frac{+0.257 + 0.021 \sin 54\,t + (0.00367 \times 54 - 0.257) \cos 54\,t}{54}$$

$$\frac{d\phi_b}{dt} = 0.021 \cos 54\,t - (0.00367 \times 54 - 0.257) \sin 54\,t$$

In addition for $P = 155{,}200$, $(v_4)_0 = 0.031$, we obtain from [33]

$$v_4 = 0.031 + 5.26\,t$$

78 Taking the duration of the second time interval again equal to 0.005 sec., we derive from the above by the substitution of $t = 0.005$, for the values of the various quantities at the end of this period:

$$\phi_a = -0.0541; \quad \frac{d\phi_a}{dt} = -0.1533; \quad \phi_b = 0.00382; \quad \frac{d\phi_b}{dt} = 0.0352$$

$$v_4 = 0.05736$$

whence by [32]

$$v_4 = 4.83 \times 0.0541 + 6.85 \times 0.0352 + 0.05736 = 1.034 \text{ ft. per sec.}$$

The values of ϕ_a, ϕ_b, and v_4 at the end of the present time interval are laid off in Figs. 3, 4 and 9, respectively.

79 *Third Time Interval.* The values of ϕ_a, $d\phi_a/dt$, ϕ_b, $d\phi_b/dt$, v_4, and v_4 at the end of the preceding period are the initial values for the present time interval. Thus we have

$$(\phi_a)_0 = -0.0541; \quad \left(\frac{d\phi_a}{dt}\right)_0 = -0.1533; \quad (\phi_b)_0 = 0.00383; \quad \left(\frac{d\phi_b}{dt}\right) = 0.0352$$

$$(v_4)_0 = 0.05736; \quad (v_4)_0 = 1.034$$

80 According to Fig. 2, the motive force corresponding to an absolute piston speed of 1.034 ft. per sec. is $P = 138{,}000$ lb., whence from [30a] and [30b] we derive

$$Q_a = -7.76 \times 10^5; \quad \text{whence} \quad \frac{Q_a}{\alpha_a p_a} = -1.815$$

$$Q_b = 1.043 \times 10^6; \quad \text{whence} \quad \frac{Q_b}{\alpha_b p_b} = 0.2384$$

81 The substitution of the values of $(\phi_a)_0$, $(d\phi_a/dt)_0$, $Q_a/\alpha_a p_a$, $(\phi_b)_0$, $(d\phi_b/dt)_0$, $Q_b/\alpha_b p_b$ in [26*a*], [26*b*], [27*a*] and [27*b*] results in the required equations for the third time interval. Continuing in this manner we can calculate the values of the normal coördinates ϕ_a and ϕ_b with a degree of accuracy which can be adjusted to all needs by the proper selection of the durations of the time intervals. The criterion, of course, is that the motive force for one time interval and the next must not show too great differences. In the present example, wherever necessary the duration of the time intervals has been taken at 0.005 sec., otherwise at 0.01 sec. Having derived the values of ϕ_a and ϕ_b, the relative displacements are calculated therefrom by means of [31]. Finally, the rope tensions are obtained by the application of [3*a*], [3*b*] and [3*c*].

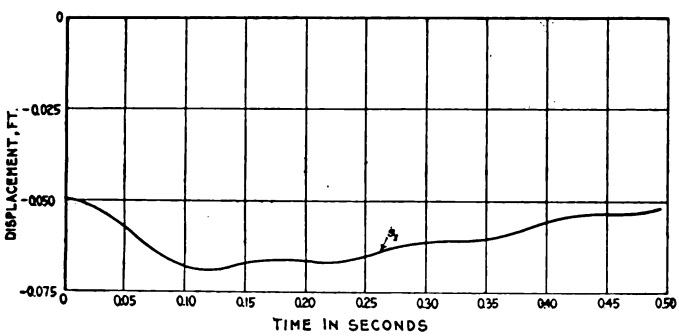

FIG. 5 RELATIVE DISPLACEMENTS OF LOAD *A*

6 CONCLUSIONS

82 The results of the above calculations are shown by graphs in Figs. 3 to 12. Owing to the wide variations in the magnitudes of the various quantities, they are mostly drawn to different scales, which should be taken into consideration when making comparisons between them. It will be observed that while all curves indicate vibrations at the start of the machine, they are, for reasons to be explained below, not as pronounced as might have been expected. Figs. 5, 6, 7, and 8 are the graphs of the relative displacements of the machine parts which are due to the elasticity of the system. In a rigid system there are of course no relative displacements nor relative velocities. Also, when the machine parts run at constant speed, the relative displacements will be constant and the relative velocities zero. These graphs are therefore a measure of the error which we commit when basing the calculations on the state of equilibrium, or

when dealing with machines as if they consisted of perfectly rigid parts.

83 The effect of the elasticity of the system is still more evident

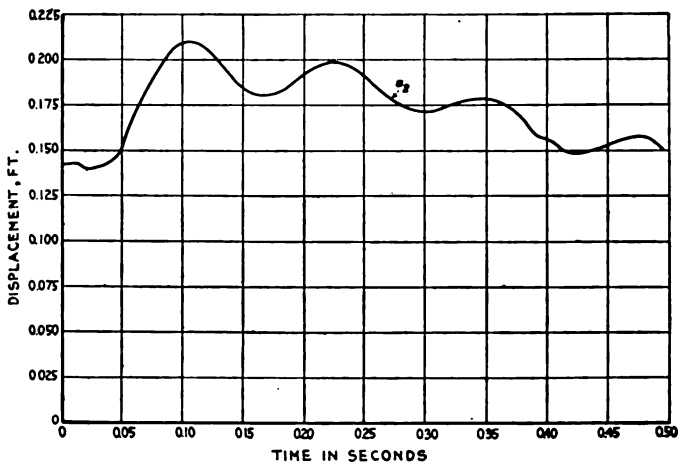

FIG. 6 RELATIVE DISPLACEMENTS OF POINTS *b* AND *c*, SHEAVE *B*

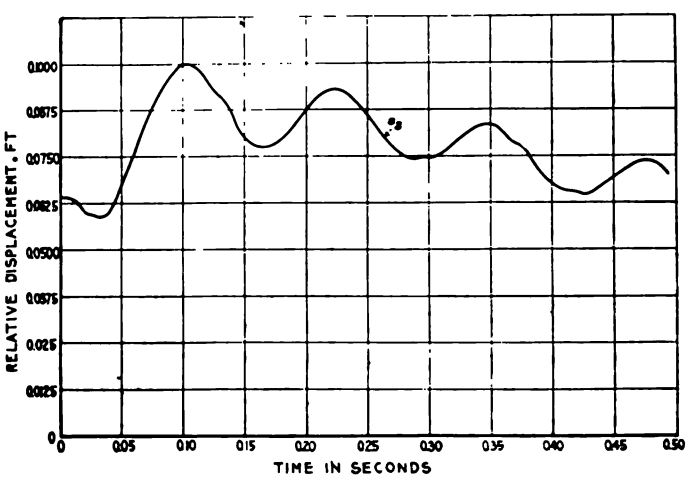

FIG. 7 RELATIVE DISPLACEMENTS OF POINTS *c* AND *d* DUE TO ROTATION OF SHEAVE *C*

from Fig. 9, in which curve No. 1 is a graph of the absolute piston speed relative to time, and curve No. 2 the absolute velocity of the load *A*. Both curves are drawn to the same scale, and are calculated by application of the fourth and first of Equations [13*b*], when equating

therein $d\phi_c/dt$ to zero. In the starting of a system of rigid parts the motion of any one part bears at all times a fixed ratio to that of the other parts. In an elastic system the conditions are different. In the present case, for example, the piston masses are small as compared with the load and are further connected to the system by comparatively very elastic members. It must therefore be expected that the application of the motive force at the start will violently disturb the equilibrium of the piston, while its effect on the heavy load will be considerably less severe. This is plainly shown in Fig. 9, wherein the absolute piston speed rises quickly from zero to 1.35 ft. per sec.

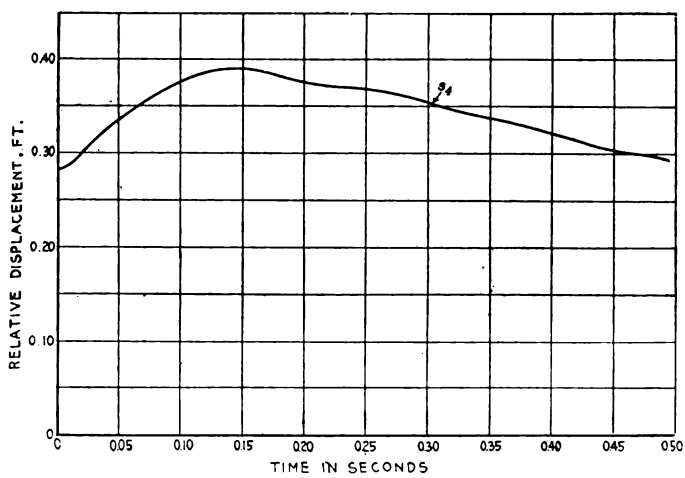

FIG. 8 RELATIVE PISTON DISPLACEMENTS

within about 0.02 sec., whereas the absolute velocity of the load even after a lapse of 0.05 sec. amounts to only 0.03 ft. per sec. It will further be seen that there is at the start no vestige of the 2 : 1 ratio between the velocities of load and piston, as would be the case in a machine of perfectly rigid parts. At $t = 0.05$ sec., for instance, the ratio is 1 : 35; at $t = 0.117$ sec. the ratio is 1 : 1; at $t = 0.3$ sec. the ratio is approximately 3 : 1.

84 That in the present case the violent rise of the piston velocity at the start nevertheless does not lead to excessive stresses in the ropes, is due to the nature of the motive force. It will be seen that the motor characteristics, Fig. 2, are such that a quick rise in the piston speed is at once accompanied by a very rapid drop in the motive force, and vice versa. For this reason large variations in the

absolute piston speed cannot persist, as is borne out by the smoother course of curve No. 1, Fig. 9, after its first violent rise. Thus the phenomena at the starting or stopping of machines depend not only on the inertia and elasticity of the various parts and on the magnitude of the motive force, but also to a very large extent on the latter's nature. In the hydraulic machine, for example, the drop in the motive force is approximately proportional to the square of the piston speed.

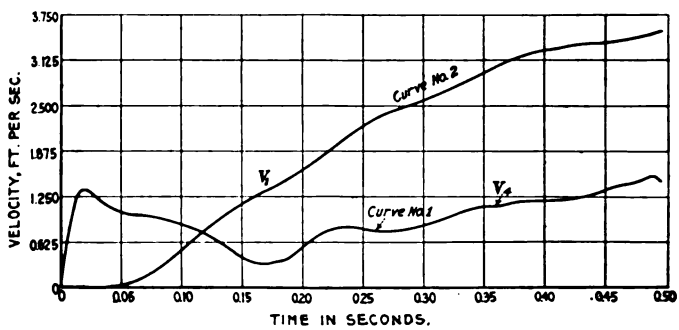

FIG. 9 CURVE NO. 1: ABSOLUTE VELOCITY OF PISTON. CURVE NO. 2: ABSOLUTE VELOCITY OF LOAD *A*

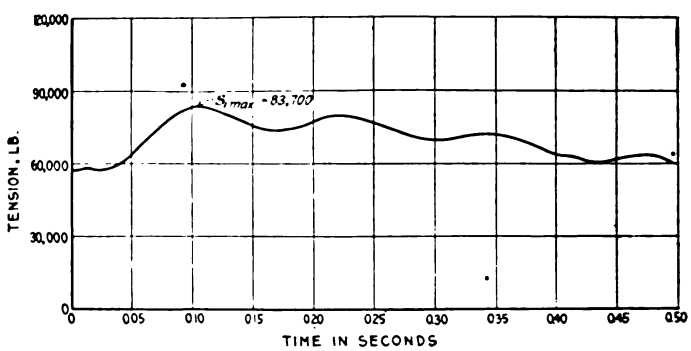

FIG. 10 TENSION S_1 IN ROPE *ab*

Evidently the results would have been much more severe had the drop been directly proportional to the piston speed. Other factors of importance are the distribution of the inertia and elasticity throughout the system. Small motor masses and a heavy load create, as we have seen, unfavorable conditions, which may, however, be relieved by connecting the motor to the remainder of the system by very elastic members.

85 Since the motor characteristics in the present case are such

that rapid variations in the absolute piston speed cannot persist, it is of course clear that the vibrations at starting, although present, cannot be very pronounced. It follows that the tendency of the present motive force to suppress vibrations will be much more effective with the normal coördinate ϕ_a, which is of preponderating influence. This, indeed, is reflected in the graphs of the normal coördinates ϕ_a and ϕ_b, Figs. 3 and 4, from which it will be seen that Fig. 4

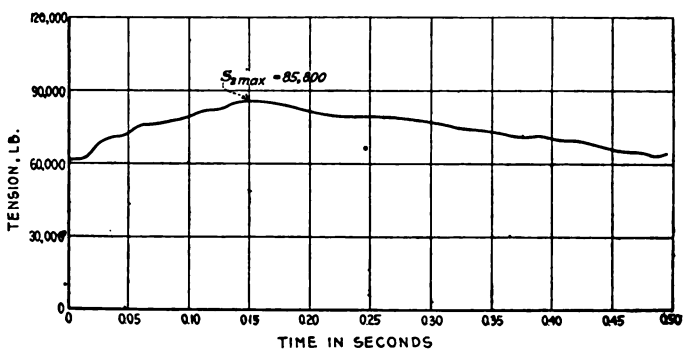

FIG. 11 TENSION S_2 IN ROPE *cd*

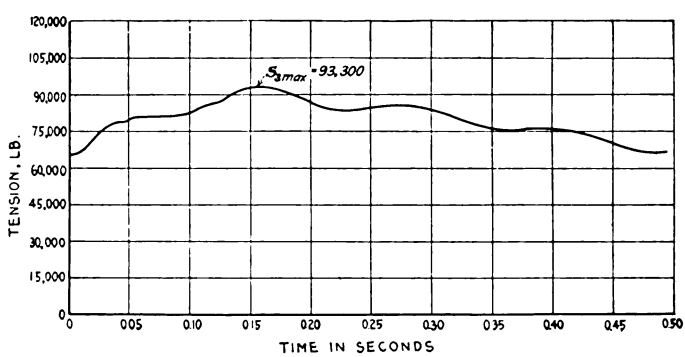

FIG. 12 TENSION S_3 IN ROPE *ef*

plainly has the nature of a vibration, while little of a vibration is noticeable in the graph of ϕ_a (Fig. 3). Attention is called to the fact that the ordinates of Fig. 3 are drawn to a scale ten times as large as that of Fig. 4.

86 The tensions S_1, S_2, S_3 in the ropes *ab*, *cd* and *ef* as they vary with time are shown in Figs. 10, 11 and 12. In the state of equilibrium S_1 = 58,000 lb., S_2 = 61,000 lb., and S_3 = 64,300 lb. During the start, however, we find that $S_{1\,max.}$ = 83,700 lb., $S_{2\,max.}$ = 85,000 lb.,

and $S_{3\,max.} = 93{,}000$ lb., exceeding the forces existing in the state of equilibrium by 44.2 per cent, 40.5 per cent and 45 per cent, respectively.

87 Knowing the maximum forces in the ropes, the calculation of axles, supports for sheaves, etc., may proceed by the ordinary methods of the theory of elasticity. It will be seen that the maxima of the forces S_1, S_2, S_3 are not very considerably in excess of their values in the state of equilibrium. This is due to the nature of the motive force, which, as already explained, has the tendency to suppress vibrations.

88 Whatever the excess may be, it is clear that it can never be guessed at, but is obtainable only at the expense of painstaking calculations. Particularly in the case of heavy machines a high degree of accuracy is required since commercial considerations necessitate the allowance of high unit stresses. The method developed by the writer has the advantage that it has for its starting point the general energy equation, from which, as shown, all of the required formulæ are derived. The general energy equation of a machine is seldom difficult to obtain, and its derivation has here been explained in sufficient detail for ready application to other cases.

DISCUSSION

S. E. Slocum[1] (written). The author's method for including the work of deformation in the energy equation for machines when starting or stopping, offers very interesting possibilities. The work of deformation has proved a very useful concept in various other lines, such, for example, as in analyzing statically indeterminate structures by the method of least work, and this new application will apparently afford a considerable refinement in the calculation of stresses in machine parts.

In the application of his method to the hydraulic machine used as an example, the author reduces all angular motion to equivalent linear motion. It would certainly simplify the solution considerably to express the kinetic energy of rotation in the standard form $\frac{1}{2} I\omega^2$, where I denotes the moment of inertia of the rotating part and ω is its angular velocity, as the relation $v = r\omega$ is always available for coördinating these velocities. The use of the ordinary expressions for angular motion would do away with such artificial

[1] Professor of Applied Mechanics, University of Cincinnati.

concepts as the "aggregate mass of the machine reduced to the piston."

The use of the unfamiliar normal coördinates serves to show the generality of the method, but complicates the solution. In the case of a simple machine like the one chosen for illustration, it would seem that the solution could be obtained directly in terms of the given quantities, with the advantage of keeping the physical meaning of the process constantly in view. This is not intended as a criticism of the method used; but in presenting a new idea it is for the most part desirable to put it in as simple a form as possible in order to make it more generally available.

It is interesting to note that the author finds that the maximum tensions in the ropes do not greatly exceed those for a state of equilibrium. The effect of the elasticity of the system, in fact, serves to relieve the strain due to the shock of a sudden start or stop. A rope, however, is a poor form of member in which to store up potential energy. A more instructive case would be the Hotchkiss type of drive recently introduced for automobiles; in this no torque tube or radius rods are used, but the rear springs take both the torsional strain on the axle and also drive the car. The effect is to relieve the sudden jerk in starting which occurs in a machine driving through a rigid torque tube and yoke attached to the frame. The flexibility of the Hotchkiss drive, however, has certain drawbacks as it keeps the brake rods in constant vibration — to such an extent as to make it difficult to keep the foot on the brake.

The same objection to flexibility would apply of course to machine tools, which are in general designed for rigidity rather than strength. In all such machines the work of deformation would be likely to be small in comparison with the inertia effects. In fact, in most machines the inertia of the moving parts when starting or stopping is the most effective cushion to shock. Just what proportion this bears to the work of elastic deformation can now be determined by the author's valuable method, and possibly in some cases the results may lead to modifications in design.

No. 1646

A SELF-ADJUSTING SPRING THRUST BEARING

By H. G. Reist, Schenectady, N. Y.
Member of the Society

A careful study of the difficulties experienced with the types of thrust bearings used in supporting the heavy loads of water wheels and the electric generators driven by them, led the author to design the flexible bearing described in the paper.

This bearing consists of a runner of a special grade of cast iron resting on a thin steel ring with a babbitted surface. The babbitted stationary ring, in turn, rests on a large number of short helical springs (ordinarily wound of ½-in. wire, 2 in. in diameter and 1½ in. long) and is held against rotation by dowel pins. A saw cut through one side does away with any tendency to dish with a change in temperature. This construction prevents the possibility of undue pressure at any point and compels each element of the surface to carry its share of the load.

Advantages to be derived from the use of such bearings are set forth and figures are given showing a reduction in friction accompanying increased unit pressure. Two designs are described and illustrated.

It has been shown that the pressure on the babbitted surface of an ordinary journal bearing varies greatly in different parts of the circumference of the bearing, being greater at the center line of the resultant load than toward the sides, and varying approximately inversely with the thickness of the oil film. Whether the greater part of this variation in pressure is due to the difference in thickness of the film or to the dragging of the oil by the shaft to a point from which it cannot readily escape, is hard to determine. The thickness of the film depends, apparently, on the load per unit area, the viscosity of the oil, and the surface speed of the shaft. Several investigators have shown that with ordinary loads of 100 lb. average pressure per square inch, the thickness of the oil film at the bottom of the bearing is about 0.0002 to 0.0003 in. With this in mind, it will readily be understood why the surfaces of the bearing have to be fitted closely to the shaft, why the supporting shell must be made rigid, and, finally, why a soft metal, which may conform to the shaft, is much better for a bearing surface than a hard one. In

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spite of all the care that may be taken, only a small part of the surface usually fits the shaft to within the aforesaid dimensions, and the load is borne on a restricted area with a pressure many times the average and often many times the pressure at the bottom of a perfectly fitting bearing. On large bearings it is difficult to prevent the metals from touching, a small part sometimes taking sufficient load to cause wiping of the babbitt at starting. "Wiping the babbitt" tends to fit the bearing to the shaft under the loaded condition, and may occur only at starting and not repeat the process afterward, due to a larger bearing surface thus being established. It is better, however, to avoid this if possible, as the particles of loosened babbitt metal may injure or destroy the good part of the bearing surface, and there is also danger of scoring the shaft.

2 In the absence of dirt or grit, bearing failures are due to the squeezing out of the oil film. The pressure necessary to accomplish this is much greater than is generally known. In one case that came to the writer's attention a pressure of 5000 lb. per sq. in. was carried for several hours and the babbitted surface was absolutely free from damage. In another case a pressure of 2000 lb. per sq. in. at a rubbing speed of 4500 ft. per min. was successfully carried. The consideration of such experience led to the conclusion that damage to properly lubricated bearings was due to failure of the oil film on so small a part of the total surface that the unit pressures on these surfaces exceeded the values just mentioned.

3 In order to maintain a film of oil of fairly uniform thickness in bearings of the constructions now in use, it is necessary that the parts which form the bearing surface should be exceedingly rigid so that the deflection of the bearing surface shall be very small. With this precaution and with very accurate fitting it is theoretically possible to maintain over the whole surface of the bearing, or a large area thereof, a film of oil sufficiently thin to support a fair pressure per inch of bearing. It is for this reason that the shells of ordinary bearings are made quite stiff so that they will do some supporting even at the ends. The ideal condition would be to have the deflection of the bearing and shaft the same, but in practice this cannot be accomplished.

4 The bearing that is to be described departs altogether from these principles and is based on the idea of a bearing surface which is so yielding, flexible and elastic that it may follow the irregularities of the rotating surface without creating at any point a pressure per square inch sufficient to destroy the oil film.

5 Many of the problems found in the construction of journal bearings are met with in the design of thrust bearings. Small bearings, up to perhaps ten inches in diameter, may be readily fitted so that at ordinary speeds the surfaces are sufficiently accurate to allow a film thin enough to support the load without danger of dragging the babbitt. The parts must be made quite rigid and the seat is usually supported on a spherical surface to correct for slight inaccuracies of alignment.

6 Thrust bearings for supporting the heavy loads of water wheels and the electric generators driven by them, are now very widely used. The difficulties in the fitting and use of plate bearings are much aggravated as the weight is increased, on account of the large overall dimensions of the supporting plate. It is true that the surfaces can be fitted quite accurately by machining, but the writer has known cases where the surfaces were turned slightly conical so that they touched hard on the inner or the outer edge. The deflection of the supporting collar on the shaft may allow the runner to be slightly dished, or there may be a deflection of the supporting surface, thereby dishing the babbitted seat or causing one side to be lower than the other. The self-adjusting spherical seat provided to correct some of these difficulties is of doubtful value on large bearings on account of the great frictional resistance which must be overcome to make it shift.

7 Thrust-bearing surfaces are usually scraped to each other, or to a surface plate, to avoid dangerously high spots; but, since the oil film is of the order of 0.0002 in. to 0.0003 in. in thickness, the difference in level must be smaller than these values. This work must usually be done without load, and, no matter how carefully done, when the bearing is loaded the parts will probably not fit each other, due to deflection.

8 A careful study of the above difficulties led the writer to the design of a flexible bearing surface pressed against the runner by springs. It seemed that this would prevent the possibility of undue pressure at any point, and compel each element of the surface to carry its share of the load. On trial, this solution proved satisfactory.

9 A typical design of a spring thrust bearing for vertical-shaft machines is shown in Fig. 1. The bearing consists of a runner of a special grade of cast iron resting on a thin steel ring with a babbitted surface. The babbitted stationary ring, in turn, rests on short helical springs and is held against rotation by dowel pins. A saw

cut through one side eliminates any tendency of the ring to dish with a change in temperature. The high base ring shown, on which the springs stand, is often used in connection with a deep housing to increase the amount of oil in the surrounding bath. The tube in the center forms a retaining wall around the shaft, for the oil. The springs ordinarily used are wound of ½-in. round wire and have an

FIG. 1 SPRING THRUST BEARING, FOR VERTICAL WATER-WHEEL-DRIVEN GENERATOR, TO CARRY A LOAD OF 300,000 LB. AT 100 R.P.M.

(View shows rubbing surface of rotating ring; stationary ring is raised to show the arrangement of springs.)

outside diameter of 2 in. and a free length of 1½ in. Under load the springs close about $\frac{1}{16}$ in., and the total pressure is well distributed. By this means it is possible to avoid excessive pressures at any point. Thus, it is safe to run with a much higher average pressure than

when there is no definite limit to the pressure which may occur over a small area.

10 It will be seen that this type of bearing differs from the solid-ring thrust bearing in that one of the bearing surfaces is made to yield at any point by using a comparatively thin plate supported by a large number of springs. While solid bearings may be used successfully for small loads, a bearing which thus automatically adjusts itself to faults in finish and in alignment is preferable for carrying very heavy weights.

11 Oil grooves are provided in one of the members and sometimes in both. In order to insure proper circulation of the oil for cooling purposes, in the case of bearings operating at low speed it is necessary to have grooves in the rotor. On high speeds these grooves may sometimes be omitted, relying for circulation only on the friction of the rotor on the oil while passing the grooves in the stator. In many cases we have had very satisfactory results by placing radial grooves in both the rotating and the stationary surface. It is our practice to have different numbers of grooves in the two plates, for instance, six and eight. With grooves in each of the surfaces we have a continuous flooding of oil on all the bearing surfaces and a very effective means of cooling. Much of the heat would otherwise have to be transmitted through the metal of the stationary part of the bearing.

12 The pressure usually allowed on these bearings is from 300 to 400 lb. per sq. in., the design permitting a very thin oil film without metallic contact. It is necessary to have the runner very smooth and free from scratches, especially any at an angle to the direction of rotation, as these might cause injury to the babbitt. The babbitted surface does not need to be scraped but is turned with a tool as smooth as is convenient. Wearing sometimes occurs in minute spots all over the plates. When this happens there is no risk of dragging the metal. The bright spots that show themselves are produced while starting and slowing down, before a pressure film is formed. When in operation the weight is apparently entirely supported on the oil film.

13 It is desirable to run bearings at a high pressure if they can be designed to do this safely, as the parts then are smaller, the rubbing speed is less, and the friction very much reduced. With this design of bearing the tendency to excessive pressure at one point is automatically relieved by the springs yielding, and while there will be some uneven distribution, a variation in pressure of two or three

times the average is comparatively unimportant and does not cause bearing failures; it is pressures of twenty or more times the average that cause injury. These excessive pressures are prevented by the construction just described. For this reason it is safer to operate this bearing with high pressures than a more rigid bearing at lower pressures.

14 The loss of alignment due to settling of foundations or other causes does not affect the bearing adversely. In one water-wheel-

FIG. 2 SPRING THRUST BEARING WITH "COMPRESSED SPRINGS" FOR MACHINES HAVING SMALL CLEARANCES

(Stationary babbitted ring is raised to show springs and dowel pins.)

driven alternator installation the striking of the field against the armature led to the discovery that the coupling between the two units had loosened, which allowed the shaft to "run out." The bearing operated without injury with over 0.03 in. vertical movement of the outer edge of the rubbing surface. This caused an uneven distribution of load on the bearing, to the extent of reducing the load on one side of the bearing about 16 per cent and increasing the pressure a similar percentage on the extreme opposite side.

15 An advantage of increased pressure in the reduction of friction is shown by the following table of comparison:

Bearing number	1	2
Revolutions per min.	200	200
Total load, lb.	300,000	300,000
Outside diameter of bearing, in.	35	46
Inside diameter of bearing, in.	17.5	17.5
Net area, sq. in.	600	1200
Pressure, lb. per sq. in.	500	250
Average rubbing speed, ft. per min.	1370	1670
Coefficient of friction	0.0018	0.0033
Kilowatt loss	16.7	38
Horsepower loss	22.5	51

16 In some designs the vertical clearance between the water wheel and the casing is very small, so that the displacement caused by a free spring under the variation of hydraulic suction is objectionable. In such cases an initial compression equal to full load, or to an overload, is put on the springs. The load will still distribute, since an overload at any point will cause the spring to close beyond the initial compression. Such a bearing is shown in Fig. 2. However, this bearing was designed to replace a roller bearing, and was so made that the parts of the water wheel would occupy the same relative positions as before. The principles used in the construction of these thrust bearings are applicable also to journal bearings and to bearing surfaces having a reciprocating motion, like the crosshead of a steam or gas engine.

17 Referring to Par. 2, it may be said that the oil film is maintained by not allowing any part of the surface to carry abnormal pressure. The writer does not know whether the front edge of a section between oil grooves is further from the runner than the leaving edge. If there is a difference, it must be exceedingly small, since the babbitted steel plates used have a material thickness. Possibly there is no such difference in the thickness of the oil film but that the oil film moves with different speeds at different places on the bearing surface, faster at the entrance from an oil groove than at the exit, and very much faster than on the side where the flow is produced by the pressure of the oil and not by adherence to the runner.

18 These bearings have been used on shafts running at speeds of 3600 r.p.m. The natural period of the springs when unloaded is very much higher than this value, and, in the writer's opinion, the bearings will undoubtedly follow irregularities at this speed. But the higher the speed, the more important it is to have the parts run true.

No. 1647

THE SMALL INDUSTRY IN A DEMOCRACY

By George H. Haynes,[1] Worcester, Mass.
Non-Member

THE purpose of this paper is to raise question as to some of the industrial implications of democracy — democracy which in government is set before us as the goal worth all this outpouring of blood and of treasure, this world anguish.

A generation ago, Gen. Francis A. Walker, then the dominating figure among American economists, declared "For one, though believing thoroughly, so far as politics are concerned, in a government of the people, by the people, for the people, I see nothing which indicates that, within any near future, industry is to become less despotic than it now is. The power of the master in production, 'the captain of industry,' has steadily increased throughout the present century."

Though describing industry as having become "despotic" in his Political Economy (1887) which for a decade became the standard text for American college students, General Walker did not think it essential to give a single paragraph to the corporation as a form of business organization, nor a page to the modern monopoly problem, and he made no mention of such a thing as a "trust." In the 30 years that have since passed, concentration and consolidation have gone forward at an unprecedented rate. The new era in industry may be admirably illustrated by examples from local history. Thus, the enterprise started by Ichabod Washburn becomes the Washburn and Moen Company. It next is absorbed by the American Steel and Wire Company, with many plants in Worcester and elsewhere. And presently that company becomes one of the many concerns, aggregating nearly 150 plants, consolidated into the United States Steel Corporation, with a capital stock of $1,100,000,000. The net earnings of this greatest of American industrial corporations were

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$295,000,000 for the past calender year, and it carries on its payroll some 200,000 employees.

There are those who see nothing of challenging inconsistency presented by the development of such an *imperium in imperio*, of such an autocratically controlled industrial army — the largest among many — in America, the leader of the world toward the goal of democracy in government. They see no incongruity in the fact that we compel the children of this host of workers to attend our public schools, and we urge the newcomers to become American citizens — at any rate, we are going to urge them to do so, from now on! — and we thrust the ballot into their hands, so that in our accepted democratic theory the vote of the newly naturalized Syrian or Polander or Croatian counts for as much as does the vote of Judge Gary himself in determining who shall be the chief executive of Gary, Indiana, or the chief executive of the state of Pennsylvania, or the chief executive of the United States of America. Yet that workman's vote or voice is not to be counted at all in determining matters as intimately concerning his own life as the conditions of his daily work or the amount of his daily wage. These matters are determined for him by the management constituted by the control of 51 per cent of the stock of the New Jersey corporation. Stock ownership by the workmen, to be sure, is encouraged by the United States Steel Corporation, as by many another far-sighted and progressive concerns; yet it is safe to say that in not one large corporation in a hundred does the stock vote of the workmen amount to enough to qualify at all the essentially autocratic management of the enterprise.

Nor is the situation greatly bettered, so far as consistency with political democracy is concerned, if the workmen be organized so that collectively they may drive a hard bargain to enforce their own demands. It used to be said that Russia was governed by a despotism tempered by fear of assassination. In democratic America, today, there is many a great industry which is controlled by an autocracy tempered by fear of revolution among its workmen in the form of a strike or sabotage.

And yet how many of us have reached the point where we believe that democracy in industry is coming, and ought to come? A striking forecast has recently come from the man who was the first president of the United States Steel Corporation, who later became the head of the company that runs the largest armament plant in the world, yet who, at the present moment — his willing service com-

mandeered by the Government — is at the head of our Emergency Fleet construction. Mr. Charles M. Schwab is reported as saying: "The time is near at hand when the men of the working class — the men without property — will control the destinies of the world. The Bolsheviki sentiment must be taken into consideration, and in the very near future we must look to the worker for a solution of the great economic questions now being considered. I am not one carelessly to turn over my belongings for the uplift of the nation, but I am one who has come to a belief that the worker will rule, and the sooner we realize this, the better it will be for our country and the world at large."

The essence of democracy, in its industrial implications, is not to be found in equality of size, or wealth, or strength. Such equality is neither desirable nor possible. The motto of democracy in industry should be that of Carnot's army of the French Revolution: "*Carrière ouverte aux talents.*"

We recognize that in a democracy the individual, however humble his station, has a right to life, liberty and the pursuit of happiness, a right to the protection of his health and safety, and to educational opportunities which shall give him a fair chance to develop according to his ability. And the war is teaching us, more plainly than we ever saw it before, that, on the other side, in a democracy the state has a right to expect from its citizens equality of sacrifice, in the sense that sacrifice shall be gaged according to their several abilities to bear burdens.

In a democracy, the industry — small as well as great — has its rights, entitled to careful safeguarding; and it has likewise its duties and special services, upon the rendering of which the very destiny of the state may depend.

Democracy is best held sane and secure against attack if the field of enterprise is kept open for men with a capacity for leadership. At present in the United States there is little to be feared from the I. W. W. or Bolsheviki. But there is grave danger for the future if no heed is now paid to the causes producing these movements, and if the field of enterprise shall seem closed to all but those of wealth or "pull."

In the field of industry as in the field of government and on the field of battle, democracy is on trial. Every forward-looking man anticipates that the industrial testing of democracy after this war will be more severe than ever before. In its relations to industry democracy must develop efficiency equal to that of autocracy, else

it is doomed to defeat. But efficiency in industry, as in war, is not alone a matter of training or equipment or centralized control — it is a matter of the spirit, of morale. Events of the past few weeks have proved that the morale of liberty-loving citizen soldiery may offset in no small degree the superior training possessed by professional fighters. So whatever conduces to better morale in industry may more than counterbalance some other highly valued elements of efficiency. In two respects, as I shall attempt to show later, the small industry distinctively and strongly does conduce to better morale: (1) in the enthusiasm which it evokes in the ambitious young employer who is managing an enterprise which is his own; and (2) in the team play which is worked out between employer and workman.

Of course, democracy must find methods not inconsistent with its own spirit to get the greatest industrial enterprises accomplished. Democracy does not imply that in the twentieth century the dial is to be turned back and that giant industries are to be split up into small units, or that a limit is to be prescribed beyond which an industry must not expand.

Democracy does imply that industries, great and small, shall be given scope to develop their capabilities up to the point where their further expansion would hamper that of others, or would prove injurious to the public interest. A generation of fumbling efforts to work out the state's proper relation to industrial control has brought into recognition some things which 40 years ago were strangely blurred.

In the first place, we recognize far more clearly than when the Sherman Anti-Trust Law and the Interstate Commerce Law were enacted, that many industries are inherently monopolistic, and that any effort to force competition in them is doomed to failure and can result only in increased cost and lessened efficiency of service. In this broad field, public interest is best to be subserved either by private operation under thoroughgoing regulation, or by government ownership and operation. Right now, under stress of war, weighty experiments are being tried out, which will throw much light on the monopoly problem.

In the second place, it is now recognized that in the so-called "trust movement," where no element of genuine monopoly has been present, a large factor has been the desire to secure the economies of large-scale production. This is a sound and constructive motive, and democracy is concerned to have such economies attained, to the

extent that does not interfere with some higher or more essential purpose.

In the third place, it is obvious that certain enterprises must be conducted on a giant scale, if at all. A copper-smelting plant, a sugar refinery, a powder plant, locomotive works, as such enterprises are now conducted, may well involve an initial investment running up into the millions. The scale most conducive to economical production is not to be predetermined by any rigid or general rule. It must be worked out in each industry and in each community according to the conditions which conduce to greatest efficiency. Each enterprise should have a fair chance for a start and for normal growth, according to the effectiveness which it develops.

Democracy craves variety and individuality in industrial development. It needs the small industry not less than the large. The point which I wish to emphasize is not so much that in a democracy the individual enterpriser needs the help and protection of the state, as that the state needs the widely distributed initiative and enthusiasm of ambitious young enterprisers.

Democracy needs to avail itself of the varied industrial talent and aptitudes of the many, and not merely of the genius of the few. There is another and a more important concern here involved than that of getting a maximum output produced at minimum cost. It is the calling forth of widely diffused and varied industrial leadership. "The magic of private property turns sand into gold." It means much for the strength and stability of a democracy if the man with capacity for industrial leadership finds scope for developing his aptitudes as his own master, in the enterprise of his own starting, and not as a foreman or as a member of the staff of some giant corporation. Right here lies a cardinal difference between industrial democracy as we would see it develop in the United States and the type of socialism which many fear. Is it not possible to keep open the door of opportunity and enable the young man to discover and develop his own aptitude, without at the same time making him the servant of the state, subject to a repression no less galling because imposed at the behest of a majority?

In recent years there has developed a new discriminating appreciation of certain advantages of the small plant in industries which are not inherently monopolistic or in which the economies of large-scale production are not a dominant consideration. Perhaps foremost among these advantages is that which relates to the element of *quality*. America has wrought her most distinctive miracles in

quantity production. Ford automobiles, to take the most notable example, are turned out by the million. But during the past year we have had our illusions removed as to the speed with which the highest type of fighting aeroplanes can be produced. Where the craftsman skill and precision are needed, more trustworthy products can be secured in the small shop than in the mammoth plant. A second advantage is found in the direct and intimate relation between office and shop in the small plant. Here the workers are still *men*, — yes, individuals, even, in the thought and under the eye of the superintendent or employer, while he is a distinct and knowable personality. This has not a few important results. In the small shop decisions are transmitted from the proprietor-manager straight to the workmen, and are carried into effect at once. Said one of our Institute graduates, a few days ago: "During the past six months we have nearly doubled our output, but we've added only one man to our office force. That puts us all under a good deal of strain." "Why not put more men on your office staff?" I inquired. His reply was: "That would mean just so much more red tape and complication. When I first went with the firm (less than ten years ago), there were in the office just Mr. A. (the inventor-proprietor), Mr. B., his partner, and one other man. *Then* things used to hum! But the more men you get in, the more cards and reports have to be made out, merely to insure *the same degree* of efficiency."

Leadership "carries" better in the small industry. The proprietor's personality and enthusiasm can lay hold upon 25 or 50 men, whereas to a force of 500 he would be simply "the boss." *Esprit de corps* and morale are of natural growth in the small shop; they are hard to develop and maintain where there is no human contact between the employer and the workmen, and where the workmen are not personally known to one another. In the small shop there can be brought home to the individual workman the direct interest which he has in maintaining both the quantity and the quality of the product; he can be brought to see clearly how his own work is discredited and his own wage lowered in consequence of the soldiering or waste of material by any member of the working force. It goes without saying that the mutual understanding between employer and employees in a small industry is a strong influence in lessening the frequency and the seriousness of labor controversies.

In fact, the advantages of the small shop are so obvious that in these days of giant corporations some of the most interesting and promising experiments in industrial management are in the attempts

to reorganize production on the small-shop basis, assigning to a superintendent and small force of men the making of a particular part or the completion of a certain series of processes in the turning out of the finished product.[1]

If it be granted that the small industry in many fields of production has distinct advantages, and that the easy and natural progress from able and ambitious workman to proprietor is accordant with the spirit of democracy and tends to safeguard it from developing industrial Bourbonism on the one hand, or industrial Bolshevikism on the other, the question presents itself: What chance has the small industry in the democracy of today? Is it getting a better or a poorer chance than a generation ago? To what extent and in what ways should a democracy, in its own interest, seek to insure that chance?

Here the first step, thoroughly in accord with the democratic principle, is to see to it that the field of opportunity is not narrowed by encroachments of monopoly not controlled in the public interest. Despite the contemptuous sniffing with which not a few self-styled "hard-headed business men" have referred to the "New Freedom" programme, I venture to believe that the spirit embodied in the Clayton Anti-Trust Law and the Federal Trade Commission Law is constructive and deserving of approval. Those laws attempt reasonable definition, where the Sherman Anti-Trust Law introduced sweeping prohibition which hastened the very development it was intended to curb. Experience has shown and doubtless will continue to show defects in these laws needing correction. But they merit a better spirit of coöperation than in many quarters they have received. The present moment in the world's history is a time more appropriate for sincere and thorough-going study of the ethics of business than for disdainful ridicule of any efforts to restrain unfair competition.

But many a small industry fails to "make good" not because of unfair practices on the part of rivals, nor from any lack of inventiveness, resourcefulness or managerial ability on the part of its enterpriser, but because he encountered exceptional difficulties in securing some one of the elements requisite to its success. If — as I believe — it is essential to the safety and stability of democracy itself that its life be constantly renewed by the upgrowth of small industries, by the direct progress of ambitious young workmen into the ranks of

[1] See Small-Shop Management for Large Plants, by F. O. Wells, president of the Greenfield Tap and Die Corporation. This article appeared in *Factory*, September 1918, p. 417.

proprietors, what steps should a democracy take to remove obstacles to such progress and to insure to the small industry a reasonable chance to work out its own salvation?

I POWER

All industries here in view are users of power. The obvious implication of democracy — though it has secured but tardy recognition — is that nature's sources of power should be made generally serviceable to the community as a whole, and should not be exploited primarily for the profit of the favored few. This idea underlies the recent movement by the National Government and by several of the states for the survey of water powers and for their conservation in the interest of all the people.

Most of the modern electric-power enterprises have been built up and are controlled by private concerns; a large proportion of them, scattered the country over, are in the hands of a comparatively few corporations which specialize in such enterprises. They are, thus, in position to bring to bear the highest engineering skill upon the solution of all technical problems, and they possess certain marked advantages in relation to maintenance and management. Here democracy is confronted by the tremendous problem of the government's relation to such enterprises, — of government ownership, with its diverse political and economic implications. A number of cities have been trying experiments under varied enough conditions to make their results of considerable interest and significance. Without exception, so far as I have observed, they report a substantial reduction in the rate made by the private corporations — it was 40 per cent in Seattle — dating from the first serious agitation for a municipal plant.

It cannot be stated too strongly that a conclusive comparison of the service rendered a community by a municipal plant and by a private corporation in competition with it can be made only by an expert, on the basis of painstaking investigation. The power rates of municipal plants are attractively low. But it must be borne in mind that those rates are in a sense not economic but "political," — rates lower than could be made by any corporation which had to pay taxes, or which could not have its deficits made up from public appropriations. Depreciation charges are likely to be figured differently in the accounting of municipal as compared with private corporations. There may be ample justification for the policy of the city's charging less than cost for electric power, just as for many years

the Post Office Department was run with a view not to its paying expenses but to its rendering the maximum service in the development of the country. But if power rates are to be fixed on that basis, the policy ought to be frankly avowed. The question as to the comparative efficiency of service to be expected from a municipal plant as compared with that of a private corporation involves many considerations which cannot be reviewed in this brief paper.

Pacific Coast cities have been pioneers in selling electric power for manufacturing purposes. A comparison of their rates would involve a maze of complications entirely inappropriate in a paper of this character. A quotation from the power rate card of a single city may serve to indicate on what easy terms the starter of a small industry may there secure his power. In Los Angeles, California, the use of the aqueduct has made possible commercial power rates running from 4 cents per kw-hr. for the first 100 kw-hr. in any one month down to 1.05 cents for from 3000 to 6000 kw-hr. Pasadena generates power by a steam plant using fuel oil, and sells her customers electric power at just one-third what it cost at the time when the city plant was projected. In Seattle the rate has been reduced to about one-quarter of what it was under the old régime, and the city's hydroelectric works are being greatly extended. In Tacoma the city has been selling power since 1897, but made no special effort along this line till 1912, when the rate was reduced from a uniform 3-cent rate to a sliding scale on which the price per kw-hr. according to the load factor runs from 24 cents (where the load factor is 10) to 0.45 cent (where the load factor is 100). And these rates are reduced by one-third where the customer agrees to take the power at certain hours and to cut off all or a large percentage of his power during the low-water period. Since 1912 there has been a marked increase in the use of electric power. Forty-two different types of industry appear upon the list of small users of power; they include machine shops, rubber factories, shipbuilding plants, meat packers, smelters, lumber manufacturers, etc. No one who reads the list can doubt that the Tacoma motor-rental system is serving effectively to diversify the city's industries and to make it easy for an ambitious young workman to start an enterprise of his own.

A most timely document is the Report on Electric Power Supply in Great Britain (made public in December, 1917) by the Coal Conservation Sub-Committee of the British Ministry of Reconstruction. What lends especial interest to this report is the fact that, by way of enforcing the necessity for a most serious consideration of the recom-

mendations which they present, they repeatedly refer to the disadvantages which the British manufacturer is sure to encounter in after-the-war competition with better-equipped American enterprises. For example:

In the United States the amount of power per worker is 56 per cent more than in the United Kingdom. If we eliminate workers in trades where the use of power is limited, or even impossible, we shall probably find that in the U. S. A. the use of power, where it *can* be used, is nearly double what it is here. On the other hand, not only are the standard rates of wages higher in the U. S. A. but living conditions are better. There is little doubt that in the U. S. A. the average purchasing power of the individual is above what it is in this country, and that this is largely due to the more extensive use of power, which increases the individual's earning capacity. The best cure for low wages is more motive power. Or, from the manufacturer's point of view, the only offset against the increasing cost of labor is the more extensive use of motive power. Thus, the solution of the workman's problem, and also that of his employer, is the same, viz., the greatest possible use of power. Hence the growing importance of having available an adequate and cheap supply of power produced with the greatest economy of fuel (p. 7). The present coal consumption would, if used economically, produce at least three times the present amount of power.

The Committee makes the following recommendations (pp. 1 and 17):

The present inefficient system of over 600 districts should be superseded by a comprehensive system, in which Great Britain is divided into some sixteen districts, in each of which there should be one authority dealing with all the generation and *main* distribution.

Sites suitable for electric generating purposes should at once be chosen where water is plentiful and transport facilities good or fuel close at hand.

Each district of electrical supply under a single authority should be a large area, with the greatest possible variety of electrical requirements and including populous centers of industrial activity. Power available from surplus gas or waste heat should be turned into electrical energy on the spot in local plants which would feed into the main distribution system.

At a time when for many months it has been necessary to subject this country's fuel supply to rigid control, on a day when many of the gas and electric light companies in New England have but a week's supply ahead, when Worcester manufacturers are facing the prospect of having to close their shops or curtail production for months, and when the bins of probably half the householders of this city are empty of coal and when no assurance can be had of more than two-thirds of a winter's supply, I have ventured to refer to this radical proposal, put forth by an eminent and responsible group of investigators, for the conservation of England's coal supply, and for the most efficient development of power therefrom, in the interest of all her people.

II CAPITAL

How shall a starting industry secure capital? In the days of Worcester's early industrial growth the necessary capital units were small and might be drawn from modest savings or secured in considerable measure from personal acquaintances. But now the situation is vastly changed. The new industry is likely to need a greater amount of capital at the start, and its founder's acquaintances are less likely than three generations ago to have the requisite funds.

At the present time some New England banks are paying considerable salaries to their representatives who go about in the community helping farmers decide how to invest borrowed capital most successfully in the development of their home farms, with the result that three parties gain: the bank, in securing a safe investment for its funds; the farmer, in getting capital, together with expert advice as to its intelligent use in his own farm problem; and the community, in securing a greatly increased production of food crops. Similar interest and coöperation may be shown by banks in the case of the starters of other small industries. Some modification of coöperative banking, as worked out in Germany and Switzerland, may enable men of character and enterprise to borrow upon their pooled credit, for the starting of a promising industry.

III LABOR

At the present time the "help" question is one of the most disheartening elements in the manufacturer's problem. Trade schools and vocational guidance are some of democracy's newer devices for affording the boy some training in fundamentals and for discovering to him and to his parents what his real aptitudes are. Public employment agencies may serve to bring employer and employee together and help distribute the labor force to the points where it is most needed. But the fundamental evil of the present situation lies far deeper. Ex-President Tucker, of Dartmouth College, declares that "the social curse of industrialism as it now exists lies in its effect upon the disposition and temper of industrial workers." He points out that by putting the worker under the dominance of the machine, by subjecting him to various conditions not of his own choosing, and by depriving him of the stimulus and incentive to private ownership, industrialism has alienated the man from his job; it has taken from him "the zest for work, than which nothing is more necessary to social progress."

One of America's most eminent engineers, Mr. Charles P. Steinmetz, has said that in every industrial enterprise there are three principal elements that need attention — the financial, the technical, and the human. He added that the I. W. W. put in their appearance where the human factor is neglected, and to the employer who disregards that human factor his admonition is: "The I. W. W. will get you if you don't watch out!"

Right here is one of the great advantages of the small industry and a prime element of its importance to a democracy. In the small shop, relations between employer and workmen still remain personal, human. The great corporations of the present day are striving earnestly to solve this problem of the human element. They are calling to their aid the psychologist and the sociologist; they engage trained experts as employment managers and organize elaborate welfare departments. But no scientific organization for "hiring and firing" and no wholesale welfare work can duplicate the results in efficiency and *esprit de corps* of the working team which can be achieved by the employer in the small industry.

In a paper recently presented before this Society, Mr. Richard B. Gregg has discussed "what it costs to hire and fire." He intimated that an annual labor turnover of 20 per cent was not exceptional, and cited cases where for several successive years it had run as high as 45 per cent, while in one department of a certain cotton mill it had last year gone over 500 per cent. The losses which such incessant shifting involve to the employer, to the workman and his family and to the community are appalling. Yet every person here knows employers in small industries who through years have kept a loyal working force, relatively permanent and having an interest and a keen pride in "their" shop, and the quantity and quality of "their" product. It was such employers and such workmen as these who gave to this Worcester community its immensely strong and diversified industrial development, so hard to maintain under the changed conditions of today.

IV RESEARCH

In one respect the small industry has been at an unnecessarily great disadvantage. The day of hit-or-miss or rule-of-thumb methods is clearly past. Yet the small industry cannot conduct scientific investigations in elaborately equipped and expensively manned research laboratories of its own. Here is a field where government, federal or state, may provide coöperation along lines similar to those

of the U. S. Department of Agriculture and of the state experiment stations. The Bureau of Standards is already doing something in the way of research work for private concerns. The laboratories of this Institute, as of scores of engineering schools and universities, have facilities which may help solve the technical problems of many a small industry, at a fraction of the cost which would be involved if the manufacturer should attempt to have this work done in his own plant.

V PUBLICITY AND MARKETING

One of the greatest disadvantages under which the small industry labors is the difficulty in getting its product continuously and effectively before the public. Private enterprise has not failed to note this need and to provide well-designed facilities to meet it. For example, the Bush Terminal Company, not content with providing the splendid buildings in connection with which manufacturing space, power, light, heat, railway and shipping facilities are furnished to its tenants, has spent $2,000,000 to erect an "International Exhibit Building" at the very heart of the day-and-night activity of New York City, on West Forty-second Street. It is where every dealer would wish to have his show room, but could not afford to do so alone. This is genuine, scientific coöperative service on the part of a far-sighted corporation, and some small industries may find great advantage in availing themselves of this opportunity.

Considerable saving and enhanced efficiency could be secured if manufacturers in related lines would coöperate in their sales work. The automobile shows offer a spasmodic and spectacular example of what may be worked out in more simple and modest fashion in many lines of industry. The coöperative fruit-selling agencies of the Pacific Coast states and the produce-marketing organizations in other parts of the country present familiar illustrations of coöperative selling. Nor is this a matter unworthy of governmental interest and aid. The medieval fairs brought business and prosperity to the towns which held them. Even in war-stricken France, the past year, certain expositions have been maintained. Our own country affords illustrations of municipal industrial museums suggestive of a development which might be greatly extended, the city providing ample and suitable halls and facilities for the display of the high-grade products distinctive of its industry — doing this not as a matter of favoritism and patronage, but taking it upon itself to advance thereby the interests of the whole city as an industrial unit, in the spirit frequently shown by a progressive chamber of commerce.

An attempt has here been made to analyze some of democracy's implications in the industrial field, and to emphasize some aspects of the American industrial system which bid fair to subject our form of government to severe strain. Emphasis has been laid upon the small industry's consistency with the spirit of democracy and its tendency to strengthen democratic institutions, and some ways have been suggested whereby through public or private coöperation the small industry, in the interest of democracy, may be given a better chance of success.

At any time these matters might have been considered of some academic interest; but right now they seem to me of a new and vital significance. I believe that it is an accurate forecast that in the future the historian will find the chief significance of this World War not in the dynastic and territorial changes which at present seem to us to be of such prodigious moment, but rather in the world-wide social and economic upheaval and revolution, for which the war is now preparing the way, and of which Russia affords a portentous example. Even before the outbreak of the war, in America as well as in Europe there were abundant signs that convulsion was impending.

The coming of peace will bring a period of tremendous readjustment. Back from the front will come scores of thousands of young officers, and millions of young soldiers, to be reassimilated into our economic and political life. That process will be vastly different from the readjustment which followed the Civil War. Back to our industrial centers these young men are to come, with a changed outlook upon life. Men who before the war had been plodding wage earners, hardly stepping outside their deep-worn rut from one year's end to another, and with no suspicion that life had anything else in store for them, have now seen other lands, other customs, They have had a great illumination. They have taken part in the greatest enterprise in the history of the human race. They have learned team play, and the immense effectiveness of disciplined coöperation. They have found within themselves unsuspected power to dare and to do and to lead. Let no one fancy that the return to the ranks of industry of these hosts of young crusaders, who have gone through hell to make the world a decent place to live in, will not add a tremendous ferment to the social and economic unrest. They are going to demand that democracy in government find its counterpart in democracy in industry; that life yield them something more than the day's wage, — that it give them something of the zest of adventure, of opportunity for advancement, of chance for independent leader-

ship. Where shall these ambitions and restless energies find an outlet?

In the strain to which our institutions are sure to be subjected in the years that lie immediately before us, the small industry may render service of incalculable importance to American democracy. It offers scope for ambitious young men to rise from the ranks to positions of leadership. It keeps relations human between employer and workmen. It gives the lie to the class-conscious radical's assertion that America is divided into two hostile camps, the bourgeois and the proletariat. When the Allies shall have succeeded in making the world safe for democracy, the small industry may have no small part in making democracy safe for the world.

No. 1648

THE WORKMAN'S HOME

ITS INFLUENCE UPON PRODUCTION IN THE FACTORY AND LABOR TURNOVER

By Leslie H. Allen,[1] Boston, Mass.
Non-Member

Recent investigations have shown that one of the most important causes of the present abnormal labor turnover is the lack of sufficient homes for the population around industrial plants. A questionnaire, prepared and circulated by the company with which the author is connected, elicited 840 replies, from which many interesting and valuable extracts are given. From a study of these replies, the general impression is gained that the causes of the labor turnover today are improper or insufficient housing, inadequate transportation, the general restlessness usual in war times, and a lack of care in placing men in positions for which they are best fitted.

One point that an investigation of housing conditions has brought out is that the type of house in which the workingman is generally lodged is not suited to his needs and is often beyond his earning power to support. Three- and four-room apartments and four- and five-room houses are an experimental type meeting with considerable success. A certain minimum requirement must be met, which should include a good-sized living room for general use, sleeping rooms of sufficient number and size to meet health demands, and adequate plumbing facilities.

THE events of the past twelve months have shown up in no uncertain way many serious defects in the structure of our social system. So many things in which we prided ourselves and rested with confidence have fallen apart or shown essential weaknesses. The earnest efforts of all who have at heart the welfare of our country and its people are needed to redesign and reconstruct the defective parts of our social machinery in order that we may maintain the leadership of democratic nations that we now hold and enjoy.

2 Among the industrial and economic problems which have disclosed themselves and are pressing for an immediate solution is that of the housing of the working classes, the subject of this paper.

[1] Aberthaw Construction Company.

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

3 Let it be recognized at the outset that this problem is entirely distinct from that of the housing of the poor, a problem of equal urgency and of greater difficulty, a problem in which we all are, or ought to be, equally interested.

4 The high wages that now prevail are not bringing to the workingman either wealth or comfort. The shorter hours that the unions have devoted so much time and effort to secure have not produced any corresponding improvement in the workman's condition. This is largely because the workman is unable to secure a comfortable home in which to enjoy his hours of leisure. If he earns high wages rents are raised by landlords and prices of other commodities go up in like manner, and in growing centers of industry houses are usually impossible to obtain. At the present time, when the cost of building is so high, new houses are not being built to accommodate the growth of population and the result is an altogether disgraceful amount of overcrowding; it is practically impossible for any workman, skilled or unskilled, coming to a new town to bring his family with him; he has to come alone and crowd in as a lodger with others.

LACK OF HOUSING A FREQUENT CAUSE OF LABOR TURNOVER

5 Recent investigations have shown that one of the most important causes of the present abnormal labor turnover is the lack of sufficient homes to house the population around industrial plants and the altogether unsatisfactory nature of such houses as there are.

6 It is hardly necessary in this paper to present figures regarding labor turnover to a meeting of engineers; it is a pressing problem that you all know more about than the speaker. Ten years ago we should have felt rather ashamed of a turnover of 100 per cent per annum. Many large plants now consider themselves very fortunate if they can get below 300 per cent. Those who do not keep track of their figures may be inclined to dispute this. But those who through their employment department keep records of their labor turnover will all bear out this general statement.

7 The fact is, that in spite of high wages the living conditions in our manufacturing centers are so miserable that a workman cannot endure a long stay in one place, and he soon throws up his job and moves on to the next town for the sake of a change in the vain hope that he will find something better than the conditions he has

just left. Such men separated from their families, and roaming from place to place soon degenerate into the "floater" class that is such a big problem to our employment departments.

RESULTS OF A QUESTIONNAIRE ON MEANS OF REDUCING LABOR TURNOVER

8 In order to bring out more clearly the importance of good and adequate housing as a means of reducing labor turnover, the Aberthaw Company has just prepared and circulated a questionnaire among employers of labor, asking for figures on their labor turnover and on the character and sufficiency of the house accommodations around their plants. Prior to this, as far as could be ascertained, no data had been assembled on this relation, although the opinion has been widely held that housing has an important influence on labor turnover.

9 Eight hundred and forty replies were received, containing a mass of most interesting information. The replies were from typical plants in the eastern and middle-western states, some in cities and some in small towns, and may be taken as a fair average statement of conditions.

10 As we expected, only a small proportion (18½ per cent) of our correspondents kept any record of their "hiring and firing;" of those who had kept records on turnover nearly a third had started keeping their records within a year.

11 Very few of those answering stated that they housed all their help, but 17 per cent owned some houses.

12 In answer to our request for an expression of opinion as to the influence of good housing, nearly all replied that it was a benefit to a manufacturing plant, tended to hold the men and made them more contented and happier, but there was some division of opinion as to whether it reduced time lost through sickness.

13 The opinion is held by all manufacturers located in large cities, such as New York, Philadelphia and Buffalo, that in very large communities housing has no bearing upon labor supply — with the exception of one firm in Detroit, which attributes a large reduction in turnover to selecting its new employees from those who live within half a mile of the plant. No firm in a very large city shows any interest in housing, although in many cases the turnover is just as large.

14 Table 1 has been compiled from the answers received. It indicates that over 50 per cent of plants reporting turnover which

have adequate housing around them have a turnover below 50 per cent, while only one-third of the plants where housing is insufficient report as low a turnover as this.

15 Combining all plants reporting a turnover of less than 100 per cent, the figures are only slightly in favor of those which have adequate housing; above this point the advantage rests with the well-housed plants.

EXTRACTS FROM REPLIES TO QUESTIONNAIRE

16 The figures obtained cannot be called conclusive — of far greater interest and value are the replies returned with the questionnaire, some of the more interesting of which follow:

TABLE 1 RELATION BETWEEN LABOR TURNOVER AND HOUSING

Turnover	Percentage of localities reporting adequate housing	Percentage of localities reporting insufficient housing
Less than 50 per cent	52.5	34
50 to 100 per cent	21	35
100 to 200 per cent	14	14
200 to 300 per cent	7	6
300 to 400 per cent	3.5	8
Over 400 per cent	2	3

17 A Pennsylvania mill has some very positive evidence of the cash value of good housing. Their manager writes us:

> Our two blast furnaces are located about twenty miles apart, and between them is the blast furnace of a rival company. We consider our housing facilities superior to theirs, and to give you an idea of the effect of this would state that for years past they have had to pay more per day, of the same number of hours, for all of the men they employ around their plant.
>
> Hardly a month goes by that we do not get some men to come to us from this rival furnace, stating that the reason for moving is, though they get less wages, the housing conditions are better around our plants.

18 A small Connecticut town of home owners seems well content, as one reply says:

> A great many of our employees own their own homes, a factor which tends to hold the men, makes them more contented and happier and is evidence of an earning power greater than in many lines of industries.

19 The experience of the general manager of one of our largest collieries confirms the views expressed. He says:

From close observation and study of results experienced at fourteen operating collieries, I can state specifically that where housing conditions excel there the better class of labor exists, as is demonstrated by higher efficiency in their work, and cleaner play during their play time.

At such of these collieries operated by this company where conveniences of a modern character have been placed at the disposal of workmen and their families, our labor is of the most efficient and also of the most stable character. We have found under these good conditions that even though the man did not fully appreciate the conveniences provided, in a great many instances after he and his family had moved away the wife has written to our superintendents asking if her husband can be placed at work again, and if a house can be obtained. At other of our collieries, especially those acquired by purchase after housing plans had been fully developed under the previous owners, we have observed that where inadequate thought and consideration had been given to house plans and conveniences difficulty was experienced in retaining the desired class of labor, even though the working conditions at the mine were equal to the working conditions at our collieries built throughout by ourselves.

20 Mr. E. H. Barnes, superintendent of the large General Electric Co. Works at Fort Wayne, Ind., writes us:

The question of companies building houses and renting them to their employees is one which very few people seem to agree on. Personally I think that any company makes a mistake in doing this. The working people as a whole suspect some ulterior reason for the company's apparent beneficence. To the average American, who usually has very fixed ideas about these matters, it is more or less repugnant.

21 From another metal-working firm we have:

We know that good housing tends to hold the men, as we find that many men give their excuse for leaving us that they cannot always obtain the kind of a house they desire.

22 A Massachusetts textile concern is desirous of seeing his men home owners independently of his company:

As a general proposition there is no question but what good housing near the plant is a benefit to any manufacturing business located in the country. We are under the impression, however, that good housing built by other people is of more benefit to the community and the manufacturing plant than housing controlled by the manufacturing plant itself.

We believe that a plan that enables the employee to build and own his own house is a benefit to the community, to the employer and to the employee.

23 A well-known crane manufacturer writes:

From the fact that nearly all of the company capital is needed in its business it is a very difficult matter for them to divert much of it to the construction of new houses, much as they would like to do so.

We find that the employees were very anxious to buy these houses, but of course, the burden of the expense will have to be carried by the company for approximately ten years.

We consider it desirable to have as many of our employees own their homes as possible, because it makes them more thrifty and their families are better satisfied ordinarily, because of the added interest.

While we have no definite statistics relative to the time lost by men who are properly housed and those who are not, we are of the opinion that a man working to pay for his own home will not lose any more time than is necessary and therefore will be on the job as steadily as it is possible for him to be. The satisfaction of owning one's own home and improving it is real. So far as we can recall we have only had one man who has bought his home leave the employ of the company in the past three years.

24 Mr. W. H. Ham, Manager of the Bridgeport Housing Company, comments on the prevailing "restlessness" and has some important and interesting suggestions to make.

Labor is restless at the present time. The single man is bound to be a rover. The young married man is somewhat better, but still has a tendency to rove and to seek better conditions and better wages because of lack of ties. The unmarried man should be free from any restraints which would handicap his ability to advance himself. My feeling is that the best way to prevent roving of the harmful type is to build up the associations in manufacturing towns to such an extent that the unmarried man may have membership in proper kinds of associations, which will teach him to advance rather than stay still. Sports for both winter and summer are very important items.

I believe in the school for advancement of knowledge in the trade and the wholesome surroundings of a sufficient number of playgrounds so that we can have athletics for a very much larger number. This will have a great deal to do with the turnover of the unmarried man in the factory.

25 Here is a manufacturer in trouble. He states:

Our problem is housing single foreigners, who are more or less transient. They keep no heat during the day, freeze all water pipes, live without furniture, and have wrecking parties occasionally. Have suggested heated barracks with common lounging room, kitchen and food store, but they do not favor this on account of group likes and dislikes.

26 Experiences like this are common where proper regulation and inspection is not carried out. But the experience of the Octavia Hill Association and many others shows that even in the worst localities tenants can be made to live decently and treat houses properly.

CAUSES OF LABOR TURNOVER AS SHOWN FROM REPLIES

27 The general impression gained from a study of these and many other letters establishes the following causes of labor turnover today:

a Improper or insufficient housing

b Inadequate transportation

c The general restlessness due in part to the abnormal war conditions

d "Misfits" — lack of care in employing men for work for which they are best fitted.

28 An important cause not touched on by any of my correspondents is the lack of proper relations between employer and employee, under which heading I would include lack of supervision of the hiring and firing of men, lack of care or interest in the men, friction with the labor unions, etc.

29 We cannot state definitely which of these is the most potent cause of trouble; but enough has been said to justify the statements made in the earlier parts of this paper on the supreme importance of good housing.

30 The lack of good and sufficient houses is now recognized as a most important industrial factor. Because of it factories are losing men, losing work, losing output and losing profit.

THE WORKMAN'S HOME: HOW IT SHOULD BE BUILT

31 One of the striking points brought out in every investigation of the housing of the working classes is that the workman is never housed in a building designed to suit his needs. New houses are always built to suit the requirements of those above him in earning power and standards of living. When such houses become dilapidated or neighborhood conditions change he enters the houses and adapts himself to them as best he can. Comparatively few workingmen need a six- or seven-room house or can afford to occupy them without subletting half of the house or taking lodgers.

32 Some of the worst housing conditions we find are in old mansions stranded by the receding tide of fashion and now occupied by four or five families, all sharing the same toilet and water supply.

33 The experiment is now being tried in many localities of building three- and four-room apartments and four- and five-room houses with much success. The workman as a rule does not desire to have the privacy of his home invaded by lodgers and welcomes the opportunity to live in a small house or apartment without them.

34 Any discussion of the kind of house he requires should be prefaced by a statement drawing a distinction between the skilled workmen and the unskilled. The former are usually Americans or live according to American standards; the latter are mostly foreign-born or negroes, receive lower rates of pay and do not desire (or if

they do desire, cannot afford) all the refinements and conveniences that are usually built in the American home.

35 There is a certain minimum, however, that we all agree should govern the design of any workman's home. He should have at least one living room for general use of an area not less than 150 sq. ft. entirely separate from his sleeping rooms, and he should have enough bedrooms for himself and for his children of different sexes to sleep apart, each bedroom having at least 400 cu. ft. of air space per occupant, and every room having direct sunlight and ventilation through windows of ample size. Every tenant should have his own private toilet equipped with water closet and bath tub, and a sink with running water in the kitchen; all plumbing should be connected to the sewer and pure water for drinking be supplied through faucets in the kitchen and bathroom.

36 American standards demand in addition separate parlors, separate dining rooms, pantries, large cellars, porches, furnace heat, electric light, laundry tubs, lavatory bowls, etc. All these are desirable and should be provided if possible, but are not essential.

37 In discussing types, methods and materials of construction ought not to be omitted. The difference in first cost between good construction and poor construction is not great and is speedily amortized in reduction of repair bills.

38 The difference in cost between a six-room frame house and one of brick, concrete or tile is at present prices less than 15 per cent. The price of the lot is the same in either case, so that the difference between a frame house costing $3000 and lot worth $600 and a brick house on same lot would be about $450 or 8 per cent. Assuming 5 per cent for interest, the saving of triennial outside painting would more than repay interest on his extra investment. By setting a lower rate for depreciation and amortization, it is possible to rent such a house at as low a rate as a frame house of the same size.

THE WORKMAN'S HOME: THE FINANCIAL PROBLEM

39 The greatest obstacle to the continuous development of industrial housing on right lines is the financial problem, so difficult alike for employee and employer to overcome.

40 Most of our workmen, skilled or unskilled, are not home owners. The margin between income and living expenses is so small that the heavy initial payments required and the difficulty of clearing off second mortgages make it extremely difficult for a man below the grade of foreman to purchase his home.

41 Where a lot is purchased with the hope of building a home later, the hope is seldom realized, and frequently such a purchase is disastrous. The home seeker, misled by specious promoters, is faced with large unexpected assessments for betterments at inconvenient times and often loses all he has invested. He rarely accumulates enough funds to start building.

42 The manufacturer, too, is faced with similar difficulties. The amount of capital required to provide housing for his men is very much greater than the amount required to house his plant and machinery, and the administration of real estate either for rental or purchase presents many difficulties.

43 Company housing is necessary for a mine or other isolated industry. Textile mills and other industries paying a relatively low wage are forced into company housing at low rentals through the desire to keep wages down, but the shoe, automobile and other highly paid trades very rarely go into industrial housing work. But at the present time in order to keep down turnover and keep labor content, all trades are finding housing to be one of the burning questions of the hour.

44 Among the essential factors in the development of a housing enterprise are the following:

a The construction of permanent fire-resisting buildings which will not depreciate rapidly and therefore will serve as security for long-term loans

b The treatment of a housing development as an artistic whole by a competent city planner and architect so as to reap as large an increment as possible in the rise of real-estate values

c The sale to the workmen of as many houses as possible on easy terms spread over a long period, the payments being arranged in a simple manner to cover insurance and taxes, as well as interest and repayments of principal

d The establishment of a definite financial policy covering rented property, including the establishment of a sinking fund to take care of depreciation and obsolescence with the intention of amortizing the equity before the mortgages fall due

e The elimination of profit in selling of houses to workmen beyond a reasonable interest on investment

f Reducing the capital invested by selling a small proportion of the property in the open market at a reasonable profit

g Careful management of property and strict regulation of tenants particularly with regard to those who become nuisances or cause undue damage to property.

45 In entering the housing field on a large scale the manufacturer can utilize the services of the large general contractor who, buying at wholesale prices in the best market, and with well-trained gangs of men, can build at lower prices than the local speculative builder and produce better-built buildings. The cost of these buildings to the manufacturer is therefore considerably less than the real-estate value. In addition to this, the value of the land plus improvements is far more than the cost of the land and improvements, and this value usually increases year by year provided that values are kept alive by trading. The manufacturer is advised not to realize on this increase in land values when selling houses to his workmen, provided he can protect himself against the workman's speculating in the land to his disadvantage, but he is certainly justified in regaining some of this value by sales to other parties in the open market.

46 In the spring the writer surveyed a six-acre tract belonging to a Connecticut manufacturer. The land, acquired when the mill was built many years ago, was valueless for manufacturing buildings owing to its topography and location and had been written down on the books at a very low figure. Plans were prepared showing the improvements necessary to develop the land for housing, the cost of the improvements being estimated at $15,000. The value of the improved land after this work had been done was estimated by local real-estate men at $40,000. On this site it is planned to build housing for thirty-five families at a cost of $120,000. The estimated real-estate value of these buildings is placed at $132,000 as the manufacturer estimated that 10 per cent would be saved by having the whole development done at once by a good general contractor. The manufacturer plans to sell ten houses of this development in the open market at a price of $6000 each; his net expenditure would then be reduced to $75,000. The real-estate value of the premises unsold is estimated at $112,000, on which he plans to secure a mortgage of $50,000, leaving a net capital expenditure of $25,000 to secure housing for twenty-five families. These houses he plans to rent to his men, or sell at cost to those who wish to buy and will undertake not to resell at once.

47 In order to protect against reselling it is advisable for the manufacturer to retain an option on the property if the man wishes

to dispose of it. Another plan is that adopted by the Goodyear Company who have added 25 per cent to the net cost of the improved land and buildings when selling, with the understanding that the 25 per cent would be returned or rebated in five years to the purchasers if they remained till then in the Company's employ. After that they were free to dispose of the property at will. This seems to be a fair solution of the problem; it would be manifestly unjust to make the option or restriction a perpetual one.

48 The calculation of land increment may seem like the proverbial "counting your chickens before they are hatched" and cannot be reckoned on in every case. In most places, however, it holds true, a striking example being that of Gary, Indiana. According to a report by Dr. Haig to the Committee on New Industrial Towns, the cost of the town site was found to be $7,057,000. The cost of improvements was $4,030,000, making a total of $11,087,000. The value now stands at $33,445,000, an increase of $22,358,000 (over 200 per cent), all of which has been dissipated among private owners and speculators.

49 A similar report by Mr. Swan on Lackawanna, New York, shows a land cost of $1,983,000, improvements $245,000 — a total cost of $2,228,000. The value now stands at $9,026,000, an increment of $6,788,000 (over 300 per cent).

50 It is generally considered that it is in a man's best interests to own his own home. Several manufacturers are making it easy for him to do so by furnishing him the home at cost and accepting small monthly payments spread out over a long term of years. It is found, for instance, at Indian Hill — the housing development of the Norton Company, Worcester, Mass. — that a man can buy a $4000 home by a 10 per cent first payment followed by payments of $25 a month, plus taxes and insurance. His monthly payments take care of interest and refunding of second mortgage and in twelve years leave him with a first mortgage of $2500.

51 Added inducements, such as "term" life insurance for the value of the home for the repayment period, add very slightly to the cost per month, and secure the ownership of the equity to the wife in the event of the man's death. Some manufacturers prefer to pay taxes also and collect in monthly or weekly payments from the purchaser.

52 In all these long-payment schemes the importance of good construction as a security against depreciation on long-term investment cannot be overemphasized.

53 In conclusion, let it be said that the housing problem, while presenting many difficulties, is not an impossible one to solve, and at the present crisis, when it has been shown to be such a vital factor in the winning of the war, it is the duty of us all to study it and endeavor to find a way in which the questions involved shall be happily and satisfactorily settled.

No. 1649

THE ECONOMICAL USE OF FUEL

A SYMPOSIUM ON FUEL CONSERVATION, PARTICULARLY IN RELATION TO CONDITIONS BROUGHT ABOUT BY THE WAR

ON the following pages will be found selections from the discussions received in response to a questionnaire issued for the Fuel Session of the Spring Meeting at Worcester, Mass., June, 1918. These are grouped under the several headings to which their subject-matter applies, and in preparing them for publication conciseness has been sought through avoiding duplication of matter on any given topic.

The questions upon which discussion was solicited are as follows:

1 What Are the Economic Effects of Impurities in Coal?
2 To What Extent Is Fuel Oil Likely to be Used as a Substitute for Coal?
3 How Can Soft Coal Be Burned Without Smoke in Marine Boilers?
4 What Are the Possibilities in the Direction of the Utilization of Anthracite Wastes?
5 What Instruments Are Useful and Desirable in the Boiler Room as Aids in Saving Coal?
6 What Is Essential to the Economical Operation of Hand-Fired Boiler Furnaces When Using Soft Coal?
7 To What Kinds of Plants and Coals are the Different Types of Mechanical Stokers Respectively Adapted, and What Is the Limiting Factor to Their Use in the Small Plant?
8 What Experience Have You Had in the Use of Wood as Fuel? To What Extent Is Wood Available as a Fuel?
9 What Coal Economies Can Be Effected in Residence Heating?
10 What Coal Economies Can Be Effected in the Small Steam Plants?
11 What Experiences Have You Had With the Storage of Coal?
12(*a*) To What Extent and Where Will the Gas Producer be Used to Produce Economies?
12(*b*) To What Extent is Natural Gas Being Used as a Fuel for Power Purposes?
12(*c*) What is the Relative Economy of the Locomotive of 1900 and Today?
12(*d*) What Proportion of the Coke is Made in By-product Ovens?
12(*e*) What are New and Important Developments in Methods of Burning Coal?

Presented at the Spring Meeting, Worcester, Mass., June 1918, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

12(*f*) What Economies Have Resulted from Recent Practice in Making Brick Settings Leakless?

12(*h*) Is Automatic Air Supply Correctly Proportioned to Coal Supply Possible?

12(*l*) Miscellaneous — School Heating — Insulation — Smoke Prevention.

Preceding the contributions on the specific topics of the questionnaire are the following five papers of an introductory character which were presented at the meeting.

THE GOVERNMENT'S PLAN FOR FUEL CONSERVATION

By David Moffat Myers,[1] New York, N. Y.
Member of the Society

As a member both of The American Society of Mechanical Engineers and of the United States Fuel Administration, it gives me pleasure to report the positive and progressive measures which have been taken by the Government for effecting fuel conservation in power plants and on railroads since the last annual meeting of this Society, in December, 1917. At that meeting, in my paper on Preventable Waste of Coal in the United States, a saving of 50 to 100 million tons per year was shown to be possible, and suggestions were made as to measures for effecting this economy. I am not overstepping the mark when I state that the national program which I will outline to you, was planned, presented and organized by members and committees of the national engineering societies.

As a result, a Fuel Engineering Division was formed in the United States Fuel Administration in Washington, under its Bureau of Conservation. This division comprised two departments — Railroads and Industries; the latter covering all power plants not belonging to railroads. The railway department was placed in charge of one of the highest authorities in this field in the country, Major Edward C. Schmidt, U. S. R., Mem.Am.Soc.M.E., who was transferred by Secretary Baker to the U. S. Fuel Administration. Major Schmidt devised and developed a plan of organization which was the work of a master mind. It was authorized by the Fuel Administration and endorsed by Mr. McAdoo's special representative. The Railway Administration determined to administer the program

[1] Advisory Engineer of the U. S. Fuel Administration.

through its own organization, whereupon Major Schmidt was given over to that administration, for the continuance of the work.

At present, therefore, the Fuel Engineering Division devotes itself exclusively to the work of conservation of fuel in stationary power plants, and in the efficient use of steam after its generation. The organization comprises the central office at Washington, with an administrative engineer appointed (or to be appointed) in each coal-using state, attached to the Federal Fuel Administration of that state. The Administrative Engineer has a consulting board of competent engineers, and a staff of technical and clerical assistants and inspectors.

The plan of organization involves centralization on essential fundamentals only. These are uniform for all states. All other features are localized and extremely elastic in their numerous ramifications. This adopted principle renders the plan workable and effective under widely varying local conditions and circumstances.

The fundamentals of the national program are as follows:

a Personal inspection of every power plant

b Rating and classification of every power plant in the country, in five classes, depending upon the thoroughness with which the owner conforms to the recommendations of the U. S. Fuel Administration

c At the discretion of the Federal Fuel Administration the supply of coal to any needlessly wasteful plant may be curtailed or stopped.

The plan is now in operation in Pennsylvania, the largest coal-consuming state, and also in Connecticut. Other states which have come in but in which the Administrative Engineer is not yet appointed, are Massachusetts, New York, New Jersey, Illinois, Michigan, Wisconsin, Indiana and Missouri.

For the office of Administrative Engineer, men are required of great organizing and administrative ability. For New York State, Mr. Edward N. Trump, Mem.Am.Soc.M.E. and vice-president of the Solvay Process Company, has patriotically accepted the nomination. Mr. Thomas R. Brown, the first Administrative Engineer actually appointed, is in charge of the western district of Pennsylvania. The second appointment was that of Mr. W. R. C. Corson for Connecticut, an officer of the Hartford Steam Boiler Insurance Company.

The standard recommendations of the United States Fuel Administration are substantially as follows:

a Fuel. That means be provided for measuring and recording fuel used each shift or day

b Water. That boiler feedwater be heated by exhaust steam or waste heat, and measured

c Air Supply. That a correct amount of air be supplied to the fuel, and that proper means be provided for measuring and regulating the draft

d Clean Heating Surfaces. That boiler heating surfaces be kept clean inside and out

e Boiler and Furnace Settings. That the furnace and setting be kept in good repair and free from air leakage

f Insulation. That exposed steam surfaces wasting heat by radiation be covered with suitable insulating material

g Engine-Room and Heating System. That wherever possible, exhaust steam be utilized to the exclusion of direct steam from the boilers. (The plant should be designed and operated to produce no more exhaust than can be efficiently utilized in heating and process work.)

h Supervision. (1) That a competent employee or committee be detailed to supervise the work of fuel conservation in the boiler and engine plants; and (2) that a competent committee be appointed in charge of the work of fuel conservation in the buildings and shops outside of the power plants.

To assist in this work the United States Fuel Administration has prepared a fifty-minute film of moving pictures, showing good and bad operation in the steam-boiler plant, methods of testing boilers, fuels, etc. These pictures will be available to each state, in connection with their publicity and educational propaganda.

The Fuel Administration is also preparing a series of official bulletins on engineering phases of steam and fuel economics. Some of these are now in press. They will include: Boiler and Furnace Testing; Flue-Gas Analysis; Saving Steam in Heating Systems; Boiler-Room Accounting Systems; Saving Steam and Fuel in Industrial Plants; Burning Fine Sizes of Anthracite; Boiler-Water Treatment; Oil Burning; and Stoker Operation.

In addition to this service, a list of competent engineers has been prepared in Washington for each state, and is available for use of the local administration. As the work develops, still further constructive assistance is contemplated for helping owners to bring their plants up to a high plane of economy.

LIMITING COAL IMPURITIES IN PENNSYLVANIA

By E. L. Cole,[1] Philadelphia, Pa.
Non-Member

PRIOR to the world war the capacity of the bituminous and anthracite mines in the United States to produce fuel was so much in excess of the demand that competition was an ample and certain factor in assuring the marketing of coal containing only a minimum of impurities.

With the steadily increasing demand for fuel, caused by the rapid development of war industries, there was a noticeable increase of the amount of impurities in anthracite and bituminous during the winter months of 1917.

These facts were known to the Fuel Administration, but because of the clamor among consumers, domestic and industrial, which was accentuated by weather conditions, for any sort of coal, action was deferred at that time. However, friendly suggestions were made to operators in the hope that the quality of coal would show improvement.

It was a vain hope.

During the arctic-like weather of the second half of last winter the demand for coal skyrocketed to a point never before reached in this country. At the same time, the quality decreased with amazing rapidity, aggravating the existing fuel famine to a degree nor readily credible.

The tonnage of inferior coal that was delivered in January was so large as to cause the Fuel Administration to take action. Dr. Garfield, National Fuel Administrator, assigned Mr. James Neale, of his staff, to assist the Pennsylvania Administration in providing and applying remedial measures in the anthracite fields.

Mr. Neale conferred with Mr. William Potter, State Fuel Administrator for Pennsylvania. With the aid of three gentlemen, who are the Fuel Chairmen in Luzerne, Lackawanna and Schuylkill Counties (Messrs. Tudor R. Williams, A. C. Campbell and Baird Halberstadt), an investigation was carried on into the amount of impurities being shipped to market.

The Fuel Administration then formulated rulings limiting the

[1] Secretary Conservation Division, Federal Fuel Administration for Pennsylvania.

percentage of slate, bone and under sizes that would be permitted by the Government in all sizes of anthracite. Inspectors were appointed in the three counties mentioned with authority to condemn all coal found below standard. The writer was directed to supervise the inspection of coal at destination points within the State.

EFFECTIVENESS OF INSPECTION AND PENALTIES IMPOSED

The effectiveness of the inspection at the mines and destination points may be indicated by the report for May. These show that less than one-half of one per cent of the daily anthracite production of more than a quarter-million tons was condemned by the Federal inspectors for the month of May. This coal was condemned at the mines, and reprepared for delivery. The vast improvement can be better visualized when it is recalled that more than 50 per cent of the marketed tonnage during January and February contained excessive amounts of impurities.

During the inspection at destination, a car of buckwheat, containing 45 per cent of impurities, was delivered at a textile mill in Philadelphia. The fireman was unable to keep steam above 55 lb., normal steam pressure being 80 lb. Production at the mill fell off 30 per cent and the cost of removing ashes increased 300 per cent. The coal company was compelled to rebate to the mill owner 50 per cent of the cost of the coal, together with an equal percentage of the freight and cartage costs.

Operators who deliver coal containing excessive amounts of impurities have been subjected to various penalties. Some cars were ordered hauled to the dumping grounds in Philadelphia; others were donated to hospitals and other non-profit-making institutions. A few cars were delivered to churches. Many cars en route to market were diverted back to the mines. In all cases the producing companies were compelled to pay the freight and other charges, and donate the coal. This action by the State Fuel Administrator had a tremendous moral effect upon the producers, and strengthened the arms of the Federal Inspectors at the mines, because publicity was given each case.

Many bituminous as well as anthracite operations have been closed because of the inferior coal shipped from them.

ALLOWABLE LIMITS FOR IMPURITIES

It is the observation of the Fuel Administration that steam sizes of anthracite containing 40 per cent of impurities are so in-

efficient in generating steam that the cost of such fuel is commercially prohibitory.

Steam sizes of anthracite containing not more than 20 per cent aggregate impurities enable firemen to maintain maximum steam under the most difficult conditions. When the amount of impurities exceeds 20 per cent, there is at once a noticeably increased amount of fuel required to maintain normal steam pressure. In addition to this, there is an increase of 10 per cent in the cost of fuel when the percentage of impurities is increased from 20 to 25 per cent, and a further increased cost in the removal of ashes.

However, expert firemen obtain fairly good results with anthracite steam sizes containing as high as 30 per cent of slate and bone, but the fuel costs show an increase of 25 to 37 per cent above the cost of the same size fuel containing only 15 per cent of impurities.

Any steam anthracite containing more than 30 per cent of slate or bone is too expensive for the manufacturer to purchase today, according to our observation. All steam coal containing more than 20 per cent of impurities is condemned when it comes under the observation of the Fuel Administration. This is so even when it is found at destination points in Pennsylvania.

IMPURITIES IN DOMESTIC SIZES OF ANTHRACITE

The effect of increase in impurities in domestic sizes of anthracite is much more marked than in steam sizes. The domestic sizes include pea, nut, stove, egg and broken coal.

Excellent results are obtained with pea coal containing 8 to 10 per cent of slate and the same amount of bone; that is, a total of 16 lb. of impurities in 100 lb. of coal.

When the amount is 11 to 12½ per cent of slate, satisfactory results are obtained but ashes must be removed at more frequent intervals, and more attention given to the fire. At the same time, there is an increase of at least 5 to 8 per cent in the cost of fuel. This applies equally to this size of coal in use of low-pressure and high-pressure service.

Pea coal containing 20 per cent of slate is worthless for low-pressure boilers. In high-pressure practice fairly good service can be obtained, but ashes must be removed at more frequent intervals and more attention be given to the fire. At the same time, there is an increase of at least 5 to 8 per cent in the cost of fuel.

In high-pressure practice fairly good service can be obtained with 25 per cent of slate, but the cost of such fuel is virtually pro-

hibitory. The larger the size of anthracite, the lower must be the percentage of impurities to obtain maximum service. No shipments of pea coal with more than 12 per cent of slate are permissible.

Chestnut gives best results when impurities do not exceed 5 per cent of slate and an equal percentage of bone (bone contains 50 per cent of carbon). Any increase above this figure is marked by inferior service. At 15 per cent fires must be carefully attended, or it will be necessary to relight them twice within 24 hours. Chestnut coal containing 20 per cent of slate is so inferior that any price for such fuel is exorbitant. All nut coal containing 7 per cent of slate is condemned by the Fuel Administration.

Stove coal containing 5 per cent of slate and 6 per cent of bone gives maximum service. At 6 per cent of slate and 7 per cent of bone the result is an increase of 8 per cent in fuel costs. This size of coal containing 8 per cent of slate and 9 per cent of bone shows the maximum possible amount of impurities that can be used by domestic consumers, discounting the high cost of such fuel. Any percentage above this renders the fuel worthless.

Egg coal should not be used when the amount of slate is more than 4 per cent and of bone more than 5 per cent. This size of coal is difficult to burn unless it is virtually free from slate. Our standard permits 2 per cent of slate and the same of bone, and because of the size of this coal (it is the size of an average fist) the slate can be readily removed by the consumer. It is much better to do so than to obtain inferior results by shoveling the dirty coal into the furnace. It may be stated that the amount of slate allowed in this coal is only equal to one piece of slate in 100 lb., and two pieces of bone in the same weight.

Broken anthracite must be virtually free from slate or bone. Even in foundry practice, as well as domestic service, it is necessary to remove all slate from this coal before it can be used. It can readily be perceived that this is imperative when the inspection schedule only allows 1 per cent of slate and 2 per cent of bone. During January many cars of broken anthracite were shipped from the mines into Philadelphia, containing from 12 to 25 per cent of slate.

IMPERATIVE NEED OF SCHEDULES FOR LIMITING IMPURITIES

There is a serious lack of authoritative data on the subject of schedules for impurities. It can be stated without question that bituminous containing more than 2 per cent of sulphur should not be used for locomotive purposes. Two and one-half per cent is

the maximum that most standard railroads accept. More than 8 per cent of slate and other impurities makes the coal dear at any price. It is expected that rulings standardizing the quality of bituminous will be issued at an early date.

The essential need of authoritative data on the subject of impurities is emphasized by the attitude of some producers. The president of one of the largest anthracite-producing companies has just urged that the percentage of impurities in anthracite be increased 2 per cent above the existing standard.

When told that this will result in delivering annually to consumers at least 1,500,000 additional tons of slate and dirt, at the highest prices ever obtained in the markets, one will readily agree that it is imperative that incontrovertible data should be at hand to sustain and make permanent the present standards governing anthracite deliveries.

To haul the proposed 2 per cent increased allowance of impurities would require about 40,000 railroad cars for a period extending from two to ten weeks, in 50 trains of 80 cars, each pulled by an equal number of locomotives, employing the necessary train crews.

The benefit of delivering one and a half million tons of slate and dirt would result in adding to the profits of producers to the extent of at least six million dollars!

The plea for this proposed allowance was based entirely upon the decreasing labor supply and the increasing needs for anthracite, but, as shown, to permit additional impurities would really increase the volume of fuel production but decrease the value of fuel delivered to consumption points. The Fuel Administration for Pennsylvania is giving serious consideration to some other method of increasing production without increasing the amount of impurities permitted in coal.

Any honest suggestion for increasing anthracite production by lowering the standard of preparation should be accompanied with an offer to reduce the market price in exact ratio to the decreased fuel value of the product.

WHAT THE SOCIETY CAN DO

At this point it may be well to offer the suggestion that this Society take up the task of obtaining data on the commercial cost of impurities of fuel. Recommendations should then be formulated by this Society to the Fuel Administration, that may crystallize

into legislative enactment that will make it a crime for unscrupulous producers to unload on consumers an inferior product, in much the same way as manufacturers of food are prohibited from delivering to our tables products unfit for human consumption.

The mining and transportation of coal requires a vast army of workers. The quality affects every person in this great country. Is it not a question worthy of the most serious consideration that men of science can give it?

To this end, the writer is authorized to say that William Potter, Federal Fuel Administrator for Pennsylvania, pledges himself and his Administration to aid any measure undertaken to insure to consumers, industrial and domestic, reasonably clean coal as a permanent institution in the United States.

Because the anthracite production is confined to Pennsylvania, the responsibility for overseeing the quality of production rests largely on the shoulders of State Administrator Potter. And it is his task to see that the vast tonnage, reaching almost to 80 million tons, from the Pennsylvania mines shall be of a quality that will enable our manufacturers to produce the essential commodities of life with a minimum amount of waste, at the prices fixed by the Government.

The Administrator invites the patriotic support of this Society in his task of keeping the quality of coal delivered to our hearthstones at a high standard, so that the home fires in the United States may be kept burning brightly while we wait the return of the "boys" who have crossed the sea to battle with the Hun that man may work out his destiny free from the shackles of despotism.

THE FUEL-OIL SITUATION

By Alfred C. Bedford,[1] New York, N. Y.
Non-Member

THE opportunity presented to me as Chairman of the National Petroleum War Service Committee to appear before you is one which I welcome and appreciate most heartily. But if you have been looking to the Petroleum Committee for an easy and quick solution of your fuel problems by the proffer of all the fuel oil you want to take the place of coal and other fuels, I am afraid I am due

[1] Chairman of the Board of Directors, Standard Oil Company of New Jersey.

to disappoint you. I am here rather to plead for special economy in the use of fuel oil and for its use only where, from the nature of the work, you cannot properly use coal.

Do not think me an alarmist. I am not trying to warn you of any petroleum or fuel oil famine. But we are all one in our wish to help win the war, and, with that end in view, we want to adjust our available resources and supplies as effectively as we possibly can to the needs of the war.

What are these needs in regard to fuel oil? First and foremost is the Navy, and in the Navy for the war purposes which we are now considering I include oil-burning cargo ships and transports, as well as the battleships, destroyers and submarine chasers.

Fuel oil is hardly less important for our ocean-going steamships, where one of its great values lies in the saving of space and weight, making possible the carrying of much larger cargoes than where room otherwise is given up to bulky coal supplies.

Our shipyards are rapidly reaching the point where large numbers of vessels will be launched. Careful computation shows that three oil-burning ships of a given tonnage of, say, 6000 tons each, will yield the same efficiency as four ships of a like tonnage burning coal. The tremendous importance of this fact of efficiency is shown when one realizes that three hundred oil-burning ships will carry the same cargo as four hundred coal-burning ships of the same size.

Meantime, the needs of our Allies have to be met, and exports of fuel oil have been for many months, and may be expected still to continue, on an ascending scale. When you add to these the requirements of the essential war industries for tempering, annealing, and other processes, for which coal is less suitable, you will realize the tremendous volume of the demand which simply has to be met.

In 1917 our consumption was in excess of our production and importations of crude oil from Mexico, and it is fair to assume an increased consumption in 1918. Our production does not at present measure up very well to these anticipated demands, but, realizing the situation, oil operators everywhere are keen to develop it with all possible dispatch.

While fully cognizant of the important needs of fuel oil as related to the manufacturing industries, the point must be emphasized that it is impossible to take oil for any one specific purpose without exerting a detrimental influence on some other branch of industry. A very large volume of oil is being used today in the manufacture of gas, and much gasoline is obtained from what would otherwise be

fuel oil. The demands for gasoline, however, are such that I must again earnestly urge upon every consumer the imperative necessity of conservation. Indeed, it may become necessary to enact definite and drastic regulations to restrict its needless consumption.

The oil men have organized so as to render the most efficient service, first, in supplying the full needs of the Government and the Allies, and second, in taking care of the ordinary business condition of the country along the lines of priority as laid down by the Fuel Administration.

What, then, are the conditions governing the present supplies of fuel oil?

So far as the Atlantic Coast is concerned, transportation is at the root of all of our troubles. While hundreds of thousands of barrels of petroleum are available in Mexico, and thousands more might be shipped from the Gulf ports, there is no way of getting these supplies North in the quantities needed. There is a shortage of shipping and the Government has found it necessary to requisition a large percentage of all the tankers in service. The pipe lines are running to capacity, and railroad conditions make it impossible to obtain any material relief by the use of tank cars. We are therefore face to face with the necessity of making the available supplies of fuel oil along the Atlantic Coast cover the present ever-increasing essential demands. Coal can be obtained. The output of coal can be increased. But the supplies of fuel oil here at present cannot.

The consequence is we must ask the factories here in the East to burn less fuel oil, or none at all where it is possible to burn coal without interfering with the efficiency of the processes involved. Particularly, fuel oil should not be used under steam boilers, either stationary or locomotive. For metallurgical work in small forges and in large forge furnaces, and those used for annealing, etc., oil has its legitimate and essential place, though even here I would urge all the economy possible. But the ordinary user of heat apparatus for the production of steam power will do well to consider coal as his best source of supply, and disregard for the time being the possible advantages of oil.

Considerable difficulties were experienced in many quarters last winter owing to the limited oil storage provided by consumers and to the irregular running of tank cars. I would therefore urge oil users to plan at once to increase their storage capacity to at least 60 days' supply, and to see that this storage, when completed, is kept full.

OIL FUEL IN NEW ENGLAND POWER PLANTS

By Henry W. Ballou,[1] Providence, R. I.
Non-Member

IN the New England states there has of late been a rapid increase in the use of oil fuel in power plants, and in a convention partly devoted to the fuel problem a brief statement of the present status thereof may be of interest.

From data privately gathered it appears that oil fuel is now used in at least 60 different power plants in New England, having a total of 83,000 boiler hp. Oil fuel is also being used in over 100 low-pressure steam plants for supplying heating systems, but such installations are mostly of a minor nature and are not within the scope of this paper.

TABLE 1 NUMBER OF OIL-FUEL POWER PLANTS IN EACH NEW ENGLAND STATE IN APRIL 1918

State	Number of Plants	Total Horsepower
Maine	3	15,600
New Hampshire	1	1,400
Vermont	2	1,200
Massachusetts	10	22,050
Rhode Island	42	42,240
Connecticut	2	957
Total	60	83,447

The power plants herein under consideration are located as roughly indicated on the outline map of New England shown in Fig. 1. They are grouped according to states as shown in Table 1, from which it may be seen that two-thirds of the power plants and over one-half of the boiler horsepower so served are in Rhode Island. As shown in Table 2, most of these installations have been made in the past three years. When classified as to type of boiler, the result is as given in Table 3. When classified as to make of oil burner in use the data are as presented in Table 4. It is estimated that in the

[1] Of the firm of Jenks and Ballou.

year 1917 about 95 per cent of all of the fuel oil burned in New England power plants was used through Hammell burners.

Oil fuel is supplied almost entirely by the Mexican Petroleum Company from three tank farms located at Providence, R. I., Chelsea, Mass., and Portland, Me., having capacities of 257,000 bbl., 165,000 bbl., and 202,000 bbl., respectively. It is said that tanks

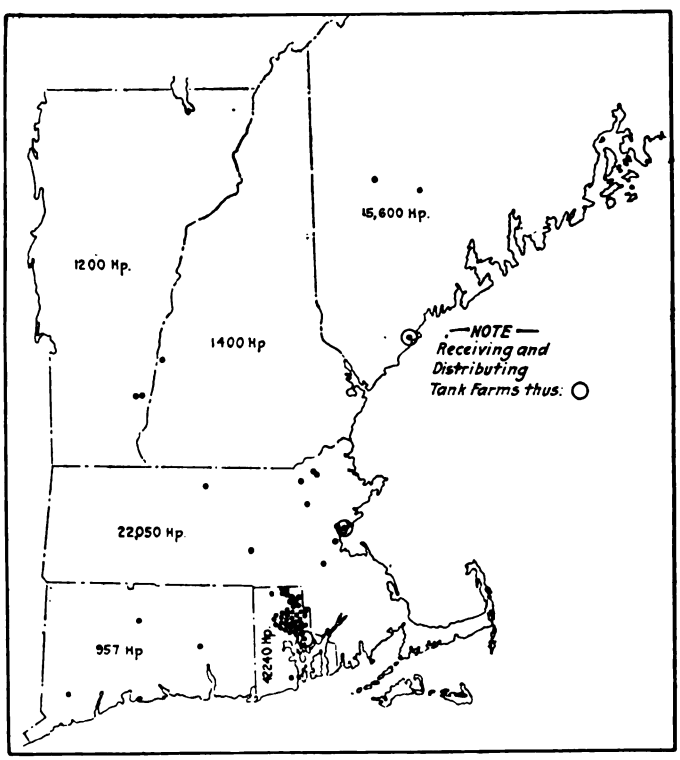

FIG. 1 DISTRIBUTION OF OIL-FUEL POWER PLANTS IN NEW ENGLAND, APRIL 1918

have been ordered to increase the capacity of the Providence tank farm to 735,000 bbl., which is roughly equivalent to 200,000 tons of coal.

All of this oil is brought from Tampico, Mexico, a distance of over 2000 miles, in tank ships. The size of these tankers has greatly increased of late, the largest running into Providence being nearly 500 ft. long and drawing nearly 30 ft. of water. Its capacity is 80,000 bbl., which is roughly equivalent to 20,000 tons of coal.

Local delivery from tank farms to power plants is by tank cars and auto trucks. Perhaps one-half of all fuel oil is delivered by auto

TABLE 2 OIL-FUEL POWER PLANTS INSTALLED IN NEW ENGLAND, 1915-1918

Year	Number of Boilers	Boiler Horsepower
1915	74	24,450
1916	79	14,315
1917	98	22,382
1918	93	22,300

trucks having capacities of from 1500 to 2280 gal. Such trucks, carrying 8 tons of oil, or enough to yield 2000 hp. for a 10-hr. day,

TABLE 3 BOILERS INSTALLED IN NEW ENGLAND OIL-FUEL POWER PLANTS, 1915-1918

Number of Boilers	Make of Boiler	Total Boiler Horsepower
130	Horizontal return tubular	22,582
88	Manning	16,525
81	Babcock & Wilcox	31,025
15	Heine	4,400
15	Stirling	3,800
5	Scotch marine	715
4	Gunboat	2,400
3	Edge Moor	1,000
2	Keeler	500
1	Aultman-Taylor	500
344	Total	83,447

will discharge their load by gravity in from 3 to 5 min. Oil trucks from the tank farms at tidewater in Providence make the round trip

TABLE 4 OIL BURNERS IN USE IN NEW ENGLAND POWER PLANTS, APRIL 1918

Make of Burner	Number of Plants	Boiler Horsepower
Hammell	55	81,040
Witt	4	1,157
White	1	1,250

to the Tamarack power house in Pawtucket (a distance of 10 miles) in 1½ hr., including both loading and unloading.

The oil is usually delivered at a temperature of from 80 to 85 deg. fahr. The quantity delivered is seldom checked by weighing

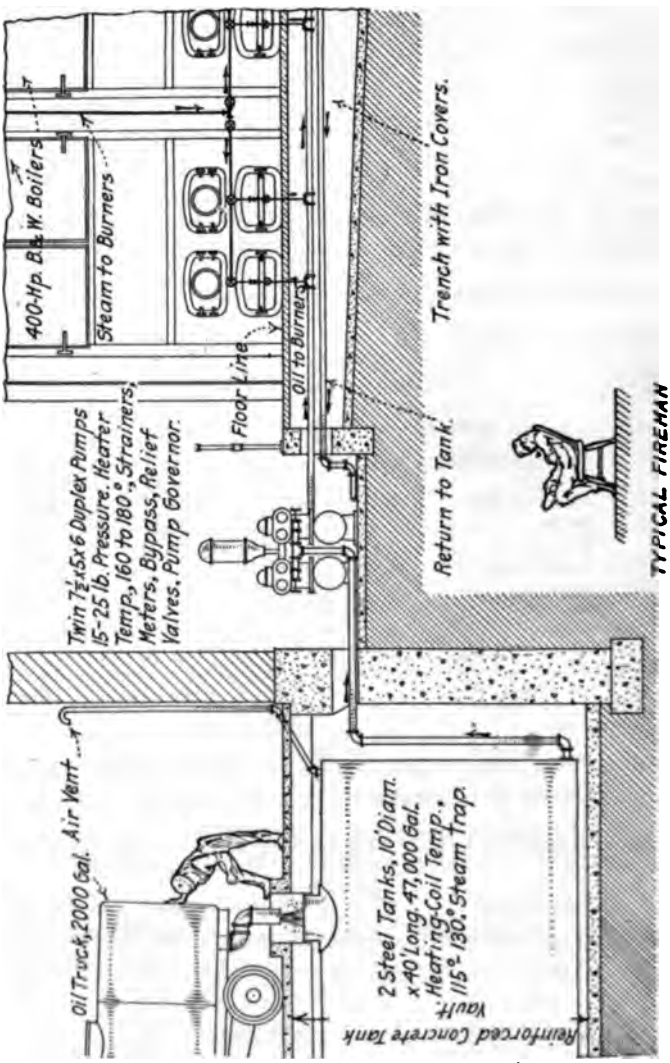

FIG. 2 DIAGRAM OF OIL-FUEL EQUIPMENT TYPICAL IN NEW ENGLAND POWER PLANTS

or by temperature observations, the "delivery slip" of the oil company usually being accepted as evidence of quantity, after observation by the purchaser's agents that the truck is full on arrival and is allowed to thoroughly drain. Analysis or other test of the oil is seldom attempted by the purchaser.

The chemical constitution and freedom from impurity of the oil appear to be remarkably uniform, especially when considered in contrast with coal. Uniformity is presumably favored by marine shipment in bulk. So far as known, there is no accumulation of water or silt in the receiving tanks at power plants. The small quantity of water in the oil, frequently about one-half of one per cent, is said to be present as a sort of emulsion.

The typical New England power-plant equipment is often about as shown in Fig. 2. Cylindrical steel tanks, of capacity to serve from a day to several weeks, are usually set in the ground or in concrete vaults. Concrete storage tanks are also extensively used. A steam coil keeps the oil in the tank at a temperature of from 90 to 120 deg. fahr., whence it passes through an ordinary duplex pump and thence to the boilers at a pressure of from 18 to 30 lb., being heated to perhaps 180 deg. fahr. by the exhaust steam from the pump. A return oil pipe discharges into the tank, thus providing warm oil at starting and discharge for the relief valve. Oil pressure is maintained by a pump governor, and meters on both supply and return pipes register quantities. Strainers, pressure gages, thermometers and twin pumps are customary. The simplicity of the typical oil equipment when compared with that for coal is of course one cause of the popularity of oil fuel.

Insurance requirements appear to have ceased to be burden some as standards of fuel and equipment have been found to be uniform and reliable. At present the two main requirements appear to be that the tank shall be below ground outside of the building walls and below the level of the pumps and boiler-room floor. Even these requirements have been modified in some cases. No difficulty is experienced in pumping oil as warm as 130 deg. fahr. with a 10-ft. suction lift; and one installation with a 15-ft. suction lift is said to be successful.

A statement of the causes and conditions which have led to this sudden adoption of oil fuel in New England may be of interest. Of course, a primal cause was active propaganda by oil and equipment companies; and the basic cause was the superiority of oil to coal. The merits of oil fuel, however, although long recognized in

other parts of this country, are somewhat of a surprise to the manufacturers of New England.

About nine-tenths of these oil-fuel installations are a substitution for coal in existing plants rather than primal installations in new plants, and it is believed that fully nine-tenths of them have been made without the advice of a consulting engineer. This statement may seem more significant than is really the case, both because in a number of instances where a consulting engineer's opinion has been sought the change to oil has not been made, and because of the excellent grade of engineering skill employed by the equipment companies in solicitation.

In general, the owner has been convinced by the remarkable contrasts between coal and oil, and the simplicity and freedom from labor troubles, ashes and dirt have appealed to him most strongly. In a number of cases additions to power plants have been avoided by the use of oil fuel, and such a feature is one to conjure with in New England.

In the judgment of managers, the minor nature of alterations in a boiler necessary to use oil fuel and the possibility of readily changing back to coal are vital features.

A few managers have appreciated the simplicity and automatic action of oil meters as compared with the several methods of weighing coal. The keeping of power-plant records of fuel consumption and rates of evaporation is greatly simplified and facilitated by oil fuel, many sources of error being eliminated.

A few plants in New England have accomplished the automatic governing of the flow of oil and of the atomizing steam. Hand control of operation is almost universal, and is now attaining a standard of excess-air proportions never reached even in the highest grade of coal plants, some tests having shown as little as 20 per cent excess air. It is inspiring to contemplate the probability that automatic regulation of the oil, the atomizing steam and the draft pressure will all become a standard reality within a few years. Then will be the golden age of regulated combustion in New England power plants.

The advantages of oil fuel are ably set forth in the TRANSACTIONS for the year 1911 in a paper by B. R. T. Collins,[1] in which there are formulated seventeen well-defined ways in which oil fuel is superior to coal. Papers by C. R. Weymouth[2] in 1908 and 1912 are also noteworthy, and the U. S. Navy tests of 1905 and of 1916 are excel-

[1] Trans.Am.Soc.M.E., vol. 33, p. 83.

[2] Trans.Am.Soc.M.E., vol. 30, pp. 775 and 797; and vol. 34, p. 639.

lent evidence, if proof were needed, that, per heat unit contained, oil fuel is from 10 to 20 per cent more efficient than coal.

In an excellent paper on fuel oil, read before the Boston Section of the A.S.M.E. in 1917, Mr. F. W. Ewing estimated that parity in the price of coal and oil is reached when 26 per cent more is paid per heat unit of oil than of coal. This would be equivalent to about a 60 per cent higher price per pound of oil. While noting that this generalization should not be taken too seriously, the writer is inclined to believe that the many collateral economies involved in the use of oil fuel cause it to be true that in many cases even more than 60 per cent extra can be paid for oil.

The saving of labor due to oil fuel as compared with coal, while in itself large, has often been given a greatly exaggerated importance. Of the operating expenses in a New England boiler plant other than fixed charges, 80 to 90 per cent are usually for fuel. Accordingly a slight variation in the cost per pound of fuel may amount to as much as the total cost of labor. It has been said that a variation of a tenth of a cent a gallon in the price of oil will offset all saving in wages due to oil fuel.

It is obvious to engineers that, assuming a dependable supply of oil fuel at a price per heat unit equal to that for coal, the latter would soon cease to be used in the power plants of New England. The choice between oil and coal is therefore a matter of supply and not of quality. The only way in which coal may rival oil fuel is in price. It accordingly becomes of interest to consider what the future may have in store for the power plants of this section.

A recent review of the coal supplies of the world by the National City Bank of New York sets forth the remarkable fact that the coal deposits of these United States exceed those of the rest of the world combined. It is also said that the coal deposits of the United States are seven times as great as those of all Europe. Of this prodigious quantity of coal deposits, a large part of the finest steam coals lie in the states of Pennsylvania and West Virginia within 500 miles of New England.

So much for deposits; how about production?

In the year 1917 the United States mined within 10 per cent of as much coal as the entire rest of the world combined. Over one-half of this vast production was in the states of Pennsylvania and West Virginia. In brief, the greatest supply of coal in the world being within 500 miles of New England, what is the case for fuel oil?

It is notable that the question of supply is not simply about *oil*, but about *fuel oil*, which latter has been defined as oil which is more valuable as fuel than in the form of refined products.

It appears that crude petroleum may be divided into two classes, namely, one with a paraffin base and the other with an asphalt base. That with the paraffin base is so valuable for its derivatives — gasoline, kerosene, lubricating oils, and a thousand others — that its price will always be prohibitive for fuel. Moreover, rapid improvement in methods of distillation has made the refined products from the lighter asphalt-base oils so valuable that many of these oils have disappeared from the fuel market. Much that was fuel oil ten years ago is no longer fuel oil. Thus it is that of the four great oil companies, each having extensive tank farms at Providence tidewater, namely, the Standard Oil Company, The Gulf Refining Company, The Texas Company, and the Mexican Petroleum Company, only the latter is furnishing fuel oil for power plants. Indeed, at the present writing the Mexican Petroleum Company is unable to take any more contracts for fuel oil, and on the face of things it appears that oil is even now more scarce than coal. The question is not as to the world-wide supply of crude petroleum, but merely as to that small part of the whole supply which may not be readily distilled.

The extremely heavy grades of asphalt-base oils from Mexico are practically the only fuel oils now available to New England. It will be shown later that this Mexican supply (amounting to 55,000,000 bbl. in 1917), though in itself of great volume, is destined to cut but a small figure in the world's supply of fuel. Consequently Mexican fuel oil will naturally gravitate toward those uses for which it will command a premium.

The question then arises as to what uses will pay a premium for fuel oil, and the answer is, those uses in which its superiority to coal are most important. The greatest of these is marine use. Consider the item of labor alone. It is generally conceded that in a large boiler plant the boiler-room labor with fuel oil may be only one-tenth of that with coal. On shipboard the labor of coal passing and trimming bunkers greatly exceeds similar labor on land. When, as on shipboard, it becomes necessary not only to transport the heavier and more bulky coal but also to transport the laborer, his housing and keep, it is unquestionable that fuel oil will command a premium for marine use as compared with its use on land. The seventeen superiorities of oil fuel formulated by Mr. Collins apply with greater force on shipboard than on land. And the same statement is true in a

slightly less measure in the case of locomotives as compared with stationary power plants.

The coal review of the National City Bank estimates the marine use of coal at 75,000,000 tons per year, or five times as much as the entire output of the Mexican oil fields. The Pennsylvania Railroad alone would take a large part of the total oil output of Mexico. Moreover, the relative ease of marine transportation of fuel oil will cause it to displace coal in places that are remote from coal deposits and difficult of access. Already, in 1917, over 3,000,000 barrels of this fuel oil went to the west coast of South America.

While prophecy is ever hazardous, it is probable that in the long run the use of fuel oil n New England will be confined to those special uses and sporadic cases which, for one abnormal cause or another, can afford to pay the premium that oil fuel will command for uses outside of power plants. Oil fuel will within a few years become a luxury for power plants.

The kinds of power plants which may be warranted in paying the premium that oil will ultimately command for transportation uses might include those plants which must maintain banked fires for considerable periods, such as plants auxiliary to water power or boilers serving fire pumps.

The premium may also be paid by small, prosperous plants in cities where smoke, dust and dirt are especially objectionable, coal storage difficult, ashes disposal expensive, and the labor expense and managerial oversight disproportionately burdensome.

In a word, oil fuel is incomparably superior to coal; but that very superiority, together with its relative scarcity, will ultimately debar it from New England power plants.

Just at present the user of oil fuel is enjoying those benefits incidental to extreme labor scarcity and abnormal prices for coal, and the lucky few who happened to have long-time contracts are reaping a golden harvest; but these conditions are ephemeral. Doubtless the whole cost of many oil-burning installations will be saved well within a period of five years.

The present rapid increase in the use of fuel oil in New England power plants is but a lucky incident in the marketing of a great natural product. Immense as is its absolute volume, the insignificance of its relative volume as a source of world-wide fuel has thus far been the main obstacle to the adoption of Mexican oil on the high seas. That obstacle is rapidly disappearing and, regrettable though it be, it is inevitable that its very virtues will ultimately deprive the power plants of New England of fuel oil.

THE FUEL PROBLEM IN THE MIDDLE WEST

By A. A. Potter, Manhattan, Kan.
Member of the Society

THE cost of producing power has increased in the various power plants of the Middle West from 15 to 60 per cent during the winter of 1917–1918. The Detroit Edison Company reports that for 1917 the total operating expenses were 35 to 40 per cent greater than in 1916. The Quincy (Ill.) Gas, Electric and Heating Company states that the increase has been 40 per cent. The cost of production in the Sioux City (Iowa) Gas and Electric Company has been increased by 60 per cent. The Meridian (Miss.) Light and Railway Company gives the cost as nearly double as compared with normal years.

The increased cost of producing power has been due to:

a The increased cost of fuel

b The necessity of burning fuels of different grades with equipment suitable for one particular grade

c The greater amount of ash and other non-combustible matter

d The increased cost of labor and the poorer quality of labor available

e The increased cost of repairs, supplies and new equipment.

INCREASE IN COST OF FUEL

The Commonwealth Edison Company, of Chicago, Ill., reports the cost of coal per ton, for January 1916, 1917 and 1918 as $1.78, $2.72 and $3.14, respectively. A large power plant in Indiana paid for coal an average of $3.60 per ton during the winter of 1917–1918, as compared with $1.66 during the winter of 1915–1916. A large power plant in Omaha, Neb., paid for fuel during the winter of 1917–1918 at an average rate of $4.45 per ton as compared with $2.85 in normal times. In Kansas power plants the cost of fuel has increased about 70 per cent as compared with normal years. The Jackson Light and Power Company, of Jackson, Miss., report an increase in the price of coal from $2.12 to $4.48.

GRADES OF FUEL USED

The majority of the power plants in the Middle West burned any grade of fuel they could secure and were forced in most cases to

go to the open market for their supplies. Plants using bituminous screenings, slack and mill run were forced to burn mine run and even screened nut and lump coal. The use of lump coal necessitated in some plants additional expenditures for crushing before the fuel could be used with certain types of stokers.

Several plants in Illinois used coke breeze. Several plants in northern Louisiana and in the other southern parts of the Central West used wood and wood waste to a limited extent. In North Dakota greater use was made of lignite slack.

Some efforts were made in several states to use fuel oil in place of coal, but it was found more expensive than coal, and, in the majority of cases, more difficult to secure on account of the shortage of tank cars. The power plants located near natural-gas fields experienced a great shortage of gas during the past winter and had to use fuel oil. In some plants this change meant an increase in operating costs of several hundred per cent. In the largest portion of Texas, lignite and bituminous slack were cheaper for power-plant use than fuel oil. Substitutions for coal were found impractical in most cases.

In several cases the fuel scarcity and high cost resulted in the greater use of coal near the producing point, but in most cases it was a question of keeping the plants going, irrespective of the price of fuel.

The fuel situation in the power plants of Iowa, Kansas, South Dakota, Texas, and Oklahoma was not as serious as in the more populous states of the Middle West. Many of the smaller power plants either had considerable fuel in storage or reduced their load. The majority of the plants in the Middle West were affected more by the quality than by the scarcity of fuel.

IMPURITIES IN COAL

In general, the ash content in the fuel used during 1917–1918 was at least 5 per cent greater than in former years on account of the faulty methods at the mines. Power-plant engineers feel that the high ash content is greatly responsible for the fuel shortage and for the increased operating costs. In ordinary times fuel containing more than 30 per cent ash would be condemned for use in boiler-room furnaces. During the winter of 1917–1918 some power plants were forced to use fuel containing 35 per cent ash.

COST OF LABOR

The cost of common labor has increased in the various parts of the Middle West from 25 per cent to 100 per cent. Operators and

firemen in power plants are receiving more pay, but in rare cases is the increase as great as 25 per cent when compared with normal times. The cost of manufacturing power has probably been more affected by the poor quality of power-plant operators and labor available than by the increased cost of such labor.

EFFECT OF INCREASED EXPENSES AND FUEL SCARCITY ON ISOLATED PLANTS

In a few cases the increased operating expenses and the scarcity of fuel had a distinct tendency to eliminate isolated plants and to transfer the load to central stations. This was especially true where the rates of central stations are maintained constant by law. The large central stations in most cases, however, were not too vigorously soliciting business on account of the increased costs of fuel, labor, material and new equipment. Some power-plant managers insist on a coal-and-labor-cost clause in connection with contracts for power. Public utilities complain about the difficulties which they are experiencing in financing improvements.

Many power companies are more concerned on account of insufficient plant capacity than because of the increased cost of fuel. Improvements and extensions in equipment are affected by the high cost of money, by the high prices of materials and equipment, by the scarcity of skilled labor and by the difficulty of securing deliveries of materials and equipment purchased. A manager of a large central station in Indiana states that they are three years behind on expansion, development and replacement

EFFORTS FOR BETTER FUEL ECONOMY

The fuel situation during the past winter has resulted in greater efforts for fuel economy. This is particularly noticeable in the small power plants of the less populous portions of the Middle West. In Missouri, Kansas, Iowa and Nebraska the uniflow steam engine is gaining favor with small municipalities on account of its low steam consumption at variable loads. The high cost of new power-plant equipment has some tendency to delay improvements, but it is remarkable to see power plants in towns of 2000 inhabitants, or even smaller, discarding an inefficient old steam prime mover and paying at the rate of $200 per kilowatt capacity for new units in order to produce fuel economy. The use of draft gages and of other measuring instruments is increasing in the boiler room, greater attention is given to the utilization of exhaust steam in non-condensing plants,

more pipe covering is used, greater attention is being given to boiler settings and furnaces, heating surfaces are kept cleaner, and definite efforts are being exerted for the more economical utilization of fuel in the power plant.

WORK OF THE FUEL ADMINISTRATORS

The work of the Fuel Administration Boards of Iowa, of Louisiana and of Illinois are particularly creditable. The fuel-conservation campaign in Iowa consists of:

a Inspection of boiler rooms and heating plants, with recommendations as to improvement in equipment and operation, and instruction of firemen in proper firing methods

b Talks to groups of engineers and firemen on combustion and firing methods

c Talks to general audiences on the economical use of fuel in the home, and on firing house furnaces; and

d Dissemination of information on burning soft coal in house furnaces. Inspections of house-heating plants were made to a very limited extent.

Iowa State College at Ames furnished seven engineers to carry on this work, each of whom spent during the past winter from two to twelve weeks making inspections and giving talks and demonstrations. Their services were available to any city or town in the state without charge except for traveling and hotel expenses. These expenses were small and were generally met by commercial clubs, which, under the direction of the Fuel Administration, also handled the advance publicity for the campaigns.

Prof. D. C. Faber of the Iowa State College, who is the consulting engineer for the Federal Fuel Administration for Iowa, gives the following in his recent report:

Thirty-four cities and towns asked for this service, including practically all of the larger cities of the state. 1354 plants were inspected, and 80 talks given to a total of 7330 people.

The boiler-plant inspections were made to point out defects in equipment and operation, and to give the firemen proper instructions in firing methods. The inspectors were equipped with draft gages, CO_2 recorders, and thermometers for measuring flue-gas temperatures. The inspections varied from casual inspections to complete investigations of combustion conditions, as circumstances required. It is not possible to enumerate the defects found by the inspectors, but a few of the commonly found faults were: leaky boiler settings; uncovered steam pipes;

failure to remove soot at frequent intervals; failure to regulate fire by use of damper in uptake; fire too thick; and firing too large a quantity of coal at one time.

In the talks to engineers and firemen, combustion, hand-firing methods and boiler-room losses were explained. These talks were accompanied by lantern slides, charts and demonstrations.

In Louisiana an extensive campaign for fuel conservation has been undertaken under Leo S. Weil, advisory engineer for the Federal Fuel Administration for Louisiana. Mr. Weil gave a complete description of his work in *Power*, Vol. 47, No. 5. Efforts were made by the Fuel Administration Board of Louisiana to substitute other fuels for coal, but these were found impractical in most cases. The fuel consumption was decreased by shutting down ice plants which operated during the winter at about one-third of their normal capacity, and the remainder of the ice plants were run at nearly normal capacity, supplying ice to those which were shut down. The attention of power-plant owners and of operators was called to the necessity of reducing waste of coal and to the desirability of coöperation on the part of both owners and operators. Suggestions concerning reduction of coal waste were sent out to power-plant operators. Mr. Weil reports very gratifying results due to the above efforts.

The Conservation Committee of the Fuel Administration of Illinois with Prof. H. H. Stoek of the University of Illinois as chairman is carrying on very constructive work among the power plants of that state in the interest of fuel economy. Those in charge of power plants are being urged to go over their equipment and to make necessary improvements. The Conservation Committee has also the coöperation of the factory inspectors of Illinois, who are bringing the matter of economy to the attention of the owners and operators of plants inspected by them.

CONCLUSIONS

The power plants of the Middle West are convinced that future emergencies can be averted by more adequate fuel storage, by greater attention to fuel economy, and by the more careful regulation on the part of the Government of the quality of fuel leaving the mines and of the fuel-transportation facilities.

Several state fuel administrators are expecting to start campaigns urging the early purchase of fuel for domestic use, and greater storage of coal by power plants during the summer. The larger power plants are expecting to store greater amounts of coal than

usual. Some plants expect to provide storage capacity sufficient for 30 days; many of the smaller plants expect to put in larger storage capacity. Considerable difficulty is being experienced in storing many of the middle-western bituminous coals on account of spontaneous combustion. Storage under water will be used to a considerable extent.

In the case of power plants using natural gas, a gas-storage-tank capacity sufficient for a 10-day period is considered practical. Such a storage capacity will take care of gas shortage during extremely cold weather.

More attention will be paid in the future to the proper furnace design for high-volatile bituminous coals. The combustion chambers of the furnaces in the majority of the smaller power plants are not large enough for the air to mix with the gases given off from the fuel bed and before such gases come in contact with the comparatively cool heating surfaces of the boiler.

Some attention should be given to the use of peat in certain parts of Michigan, Minnesota and Wisconsin for domestic use and possibly also for power generation. With the increasing scarcity and higher cost of coal and oil, low-grade fuels must be given greater consideration in connection with the generation of power.

The fuel administrators of the various states should be encouraged to secure engineering assistance, particularly in connection with the campaigns for economy in the smaller power plants. Much fuel can be saved if the operators of the small power plants can be carefully instructed with reference to the overhauling of equipment, the avoidance of air infiltration through settings, proper firing methods, correct thickness of fuel bed and other operating details which lead to the economical utilization of fuel. The institution of campaigns for fuel conservation, such as have been undertaken in Louisiana and in Iowa, will result in greater fuel economy. Such campaigns are absolutely necessary in the less populous sections of the Middle West, where the majority of the power plants are small and are operated by poorly trained attendants.

A detailed study of coal-car movements in the Middle West during the past four years discloses the fact that the average time required to move cars is extremely long. In most cases cars carrying coal will average less than 20 miles per day. When to this time is added the time required for empty cars to return to the mines, it is evident that the coal tonnage handled per car per year is very limited and very much smaller than reasonably efficient operation should

produce. This delay is due partly to the practice by railroads of throwing cars on sidings and into yards with unnecessary switching, instead of delivering them to their destination in one or two hauls. Pooling of engines, cars and routes can be made to substantially relieve this situation. Another relief can come by so routing coal as to avoid, as far as possible, the congested terminals at the larger cities. Where freight cars must pass through such cities, movements could be expedited by constructing belt lines around them. The coal shortage can also be reduced if greater efforts are made by all coal users to unload cars as soon as they reach their destination.

To avoid the recurrence of the conditions of last winter, the power-plant men will have to coöperate with the Government by providing adequate coal-storage facilities, by unloading fuel without delay after it reaches its destination, and by giving careful attention to power-plant economy. The Government will have to insist upon reasonable cleanliness of coal leaving the mines and should give more attention to the improvement in the railroad equipment and in the methods of transporting coal from the mines to the consumer.

DISCUSSION ON FUEL ECONOMY

1 *What Are the Economic Effects of Impurities in Coal? It has been claimed that when coal contains 40 per cent of refuse it becomes valueless as fuel. What has been your experience?*

W. S. Gould. During the last two years, as prices have mounted higher, the quality of the fuel shipped to market has decreased until lately the lack of quality of the so-called coal available to the power plants of the country has become a decided menace not only to our economic development but to the safety of the nation.

It makes no difference how much our railroad equipment is increased, it makes no difference what prices are fixed by the Government for coal, nor how many rules and regulations are issued by the Fuel Administrator, so long as drastic and effective steps are not taken to insure the proper preparation of the coal mined and shipped.

EFFICIENCY LOSS FROM ASH AND FROM USE OF WEATHERED COAL

The Bureau of Mines estimated that the ash of coal mined in 1917 had increased 5 per cent for the whole country, and that this

increase in the ash content meant a further loss of 7.5 per cent in the efficiency of the power plants. Some of the mining districts show a much higher increase. This means that while we produced and shipped 544,000,000 tons of fuel in 1917, the tonnage was equal in effective power-producing qualities to only 476,000,000 tons of the 1916 quality. In other words, in 1917 we mined and shipped some 70,000,000 tons simply to make up for the inferior quality. This is the real cause of our coal troubles.

Further, while the increase in the ash content was fully equal to 5 per cent, the decrease in the heat was considerably greater than 5 per cent, this decrease being due to the fact that millions of tons of weathered coal were shipped — pillar and outcrop coal and refuse from mine dumps — all of which was considerably lower in heat in proportion to the ash content than would have been the case if the coal had been freshly mined from the seam. The Fuel Administration originally encouraged these "wagon mines," the number of which increased enormously, directly cutting down the available fuel.

INFLUENCE OF SULPHUR ON CLINKER

In addition to the well-established loss in efficiency and capacity of our power plants, due to the higher percentage of the ash impurity, we should not lose sight of the further loss in efficiency and capacity due to the increase in the sulphur content of coal. Sulphur in coal affects the economy of the boilers by forming clinkers, which hinder the proper distribution of air. This improper distribution may be excess or deficiency of air.

It has been found that while the drop in the combined efficiency of the boiler and furnace averaged about 0.5 per cent for each per cent of sulphur between 0.5 and 6 per cent, the general drop in boiler capacity is about 1.5 per cent for each per cent of sulphur. The increased amount of clinker, due to the higher sulphur percentages, is doubtless responsible for this drop in the capacity, reducing the rate of combustion and therefore capacity.

Before 1916 eastern coals that carried sulphur in excess of 3 per cent were not common. Since that time the cases of 5 and 6 per cent sulphur, and some almost incredibly high, have steadily increased, until during the last winter it has been quite the exception to find coals with less than 2 per cent.

Then there is the damage that sulphur causes to the tubes, plates and grates of the equipment — a damage that is usually

difficult to measure, especially since it is generally unexpected by the plant engineer, or comes when he has no time to make exact calculations or cannot get information as to his coal.

Just two examples of the many cases that have come under our own observation may be given:

a A plant equipped with Model stokers had been using a certain coal which did not average high in sulphur — about 1.60 per cent, but of a character that often causes trouble under similar conditions. The plant had been running wild, with a low rate of efficiency, and there had been no special trouble with the grate bars, which had stood up for weeks. Better operating methods were inaugurated, and the grate bars began melting at an alarming rate, some in about a week. Ordinarily the cause of this trouble would have been laid either to the operating methods, and therefore a necessary evil, or to the grate bars. We selected, through our Library of Coal Records, a coal of equal heating value but without the characteristics of the coal being used at the plant, and the trouble with the grates ceased.

b Another case was in a plant with flat grates, hand-fired, and running at a low rate of combustion. This plant had been using a coal which was excellent so far as ash and heat were concerned, but which averaged about 2 per cent sulphur. The boilers not being forced, there had been no appreciable damage from the sulphur in the coal. A new lot of coal arriving, showing about 3.50 per cent sulphur but otherwise being about as usual, I suggested that, with their operating conditions, they would probably find little trouble from clinkering, incidentally remarking that the only probable damage would be to their equipment. The superintendent asked if that were not more or less imagination, so I suggested his making a simple test of the point. One boiler was carefully cleaned and practically new grates installed. It was arranged that the 3.50 per cent coal should be used exclusively under this boiler for one day, and then the fires pulled and an estimate made of any damage that could be observed. A few days later we received a letter from the superintendent stating that the test was run as directed, and that "after four hours the grates were entirely destroyed."

WALTER N. POLAKOV. The value of coal as used for power production is chiefly determined by its steaming capacity. Generally, there are two reasons for the condemnation of steam coals:

a When the composition and peculiarities are unfit for *existing* equipment

b When impurities make it unfit for *any* equipment.

Coals that are unfit for existing equipment or requirements should not be purchased at all, as they may be used to advantage elsewhere. The opinions on the subject advanced by miners, dealers, purchasing agents and accountants should be submitted for final disposition to engineers who are guided by facts.

Coals with a high percentage of non-combustibles were used by the author last winter in both hand- and mechanically-stoked fur-

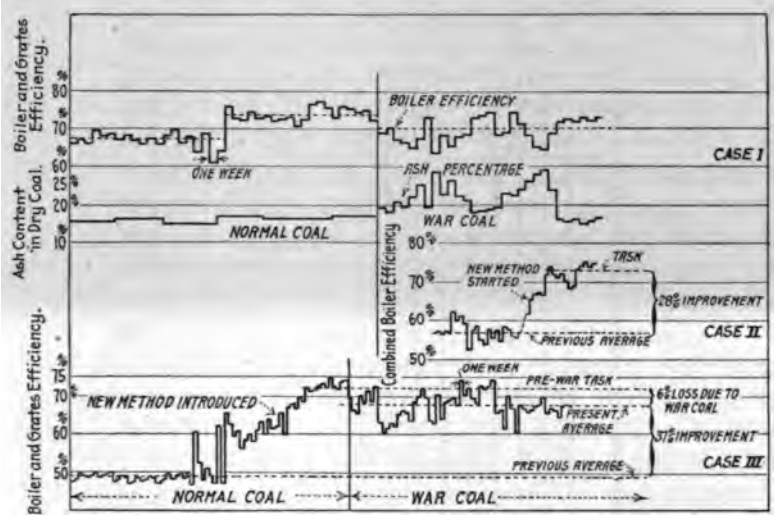

Fig. 3 Effect of Impurities in Coal on Boiler Efficiency in Typical Power Plants

Note: Task work with bonus more than offsets the harmful effect

naces. For instance, a mixture of 1 part run of mine and 5 parts of anthracite screenings was observed to show never less than 60 per cent of boiler and furnace efficiency. This mixture contained 15 per cent of ice and water, 28 per cent of earthy matter, and nearly 2 per cent of oxygen — a total of 45 per cent.

RESULTS FROM IMPURITIES IN COAL

From a large number of observations with coals contaminated with non-combustible impurities that are thrown on the market by

some dealers at the risk of the country's liberty and honor, several conclusions may be drawn:

a While the efficiency of steam generation with so-called war coals drops from 10 to 25 per cent, the improved boiler-room management based on task work with bonus invariably more than offsets this loss. (Fig. 3.)

b The steaming capacity of coal drops along a parabolic curve; i.e., with the increase of ash content the evaporation drops more rapidly in the beginning and more slowly when ash percentage is getting high. (Fig. 4.)

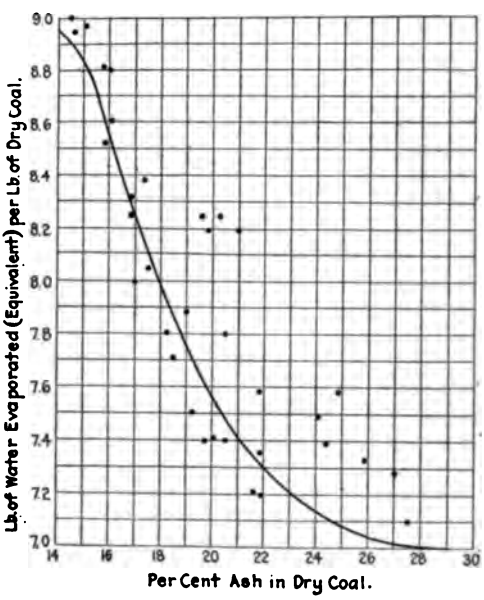

FIG. 4 RELATION BETWEEN ASH CONTENT AND EVAPORATION

c From Fig. 4 it appears that the increase of ash content from 14 to 18 per cent reduces the evaporation per pound of coal from 9 lb. to 8 lb. of steam (11.1 per cent), whereas further drop of evaporation from 8 to 7 lb. per pound of coal (12.5 per cent) corresponds with the increase of ash content from 18 per cent to 28 per cent.

It should be noted that these data are obtained from a number of hand-fired plants using mixtures of hard and soft coal for a period of over 18 months. The means of recording the performances were in all cases most rigor-

ous, specialists taking continuous checks on accuracy, firemen trained and methods of firing constantly adjusted to secure the best possible results. While the deviations of results with each kind of coal are sometimes large, due to difference in plant equipment and degree of training of firemen, the tendency of retarded drop of efficiency with higher percentage of ash remains noticeable throughout.

d While extra cost of haulage and extra expense for the labor of handling coal and furnace refuse are easily estimated, the more important, though less noticeable, loss is due to difficulties connected with the admission of the proper amount of air into the furnace. If this is judged by the rate of firing (lb. per hr.), excess of air is inevitable with coals high in ash. Similarly, if direction is given by draft indications, extra resistance of fuel bed is liable to mislead the fireman. Again, if adjustments are based on gas analyses, the improper velocity of gases through the boiler may lower the efficiency of heating surface for the sake of high furnace efficiency, ultimately at the expense of combined efficiency. Additional losses are incurred by more frequent cleaning of fires.

e By far the greatest economic effect of impure coals is the misuse of rail and water facilities for transporting the harmful, or, at best, useless, ingredients. The National Coal Association in a statement issued April 28, 1918, announces that "Interference with the war program is almost inevitable throughout the East, unless there is a readjustment soon of traffic over eastern railroads." Decrease in production of coal because of car shortage is estimated by the same authority at about 20 per cent.

f Instead of thus harassing the Government in its task of operating railways and jeopardizing the country's production at this grave moment, the coal producers could disprove the charge of disloyalty by more careful preparation of coal at the mines. Cleaner coal will, as we have seen, not only release large parts of the rolling stock engaged in transporting dirt and slate, but also reduce the tonnage required for steam generation.

g It is to be remembered, however, that half measures toward preparation of cleaner coal at the mines will not go half

way in ameliorating the present car shortage and furnace wastes. By reducing ash percentage from 28 to 21 per cent only seven cars out of every 100 will be released, yet by removing also the other half of impurities from coal (i.e., placing the quality of coal on pre-war standard) the need will be satisfied with 78 cars out of every 100 now tied up; i.e., not 14 but 22 cars may be released.

To sum up, the vicious economic effect of impurities in the coal can be overcome as follows:

a A twenty per cent car shortage may be taken care of by releasing 22 per cent through reinstatement of previous quality of coal preparation

b Further conservation of coal is possible by adopting more scientific methods of power generation and management of plants.

CARL J. FLETCHER.[1] During last winter much coal was wasted throughout Indiana due to the forced change in fuel. There are three very marked differences between the coal mined in Indiana and the coal mined in eastern Ohio, Pennsylvania and West Virginia: first, the amount and quality of the volatile matter; second, the liability to clinker; third, the form in which the impurities occur in the coal as delivered at the boiler room.

The volatile matter in eastern coal is less in volume and also higher are hydrogen, making it more easily combustible. The principal troubles in burning Indiana coal lie in lack of combustion space, which is necessary for the burning of very high-volatile coal, and a proper distance from the fuel bed to the comparatively cold boiler surfaces, which rob the furnace of heat and do not allow a sufficiently high temperature for the combustion of all the volatile matter.

Second, the clinkering of coal is due primarily to the fact that there is more iron pyrites in Indiana coal. Iron pyrites can be successfully burned without objectionable clinkering under proper conditions. More draft is required to burn Indiana coal, both to keep the grates cool and to get a proper mixture of the volatile matter with oxygen. It often happens that in planning for a change to Indiana coal the grate surface is enlarged, reducing the available draft over the fire, when the proper procedure in this case would be to increase the force of draft.

[1] Fuel Engineer, Knox County Coal Operators' Association, Indianapolis, Ind.

Regarding the difference in the form of impurities in eastern and western coal, the impurities in Indiana coal appear mostly as shale; whereas ash in the eastern coal is generally evenly distributed throughout the coal, and when eastern coal is burned it is a comparatively easy matter to free the fuel bed of ash. Shaking grates, such as are suitable for eastern coals, generally fail when applied to western coal. It does not do any particular harm to stir and mix some coals, while other fuel beds must not be disturbed. To burn Indiana coal it is necessary to have a type of grate with at least 50 per cent air space, and a grate which will crush the larger pieces of impurities and remove them with a minimum disturbance of the burning fuel.

C. E. Van Bergen.[1] The value of coal producing 40 per cent ash depends, first, on the price of coal; second, on the expense of placing it on the grates; and third, upon the cost of removing the 40 per cent ash. We estimate that 1 lb. of such a coal will evaporate, under ordinary conditions, 3 lb. of water.

Our records show that the coal we used from November 1, 1916, to March 1, 1917, evaporated 7.62 lb. water per lb. coal and contained 10 per cent ash. From November 1, 1917, to March 1, 1918, our coal contained 17 per cent ash and evaporated 6.69 lb. water per lb. coal. An increase of 7 per cent in ash content resulted in a loss in evaporation of 12.2 per cent.

W. L. Abbott. In experiments made with a chain-grate stoker, using Illinois coal mixed with various percentages of ash, the capacity and efficiency of the unit dropped gradually with an increase of ash up to 35 per cent, after which they declined rapidly to zero efficiency and capacity with a fuel containing 40 per cent ash. The fuel would still burn, but the boiler would not generate steam. The fuel used in the test was made by mixing various amounts of ashes with a clean pea coal, the ash content of which was about 8 per cent. Thus, in the final test, the coal containing 8 per cent of ash was mixed with an additional 32 per cent of impurities. A different furnace or stoker might have given a somewhat different result, but it is questionable if any other form of stoker would have handled a fire containing that great amount of readily fusible ash.

Results obtained from this series of tests, which were made by mixing ash with the coal, correspond with results obtained by the

[1] Vice-President and General Manager, Duluth (Minn.) Edison Electric Co.

Bureau of Mines in tests made in St. Louis using coals with an inherent ash content ranging up to 25 per cent, above which point the Bureau's tests did not go.

In a gas producer a fuel mixture of the kind first described would, no doubt, have given some useful results. A blast furnace always operates with a fuel mixture containing more than 40 per cent of non-combustible. If a coal contained as much as 40 per cent ash it would not be marketable, and might rather be called a bituminous shale. Marketed coal contains between 2 per cent and 15 per cent ash, as extremes, but usually less than 10 per cent. If the fuel mixture carries more, it is due to impurities which are associated with the coal; for example, a coal seam analyzing 10 per cent in a seam sample may produce mine run containing 15 per cent ash.

With increasing ash content there is a decreasing boiler efficiency and an increasing cost of the steam produced, and while coal containing nearly 40 per cent of ash may produce some steam, it is rare indeed that it is economical to use coal containing as high as 20 per cent ash.

Henry Kreisinger. The statement that when a fuel contains 40 per cent refuse it becomes valueless, cannot be applied generally, as there are places where such fuel has economic value. In power plants located near the mines, washery refuse containing less than 50 per cent combustible can be used profitably, especially if the furnaces are designed for burning such fuel.

Some time ago the Bureau of Mines made a boiler test with washery refuse containing 41.8 per cent of ash, 10.8 per cent of moisture, 47.4 per cent of combustible. The test was made under a 200-hp. Heine boiler set up with an ordinary hand-fired furnace with plain grate. About 75 per cent of the rated capacity of the boiler was developed with average overall efficiency of 47.5 per cent. Of the 47.4 per cent of combustible in the fuel, 8.6 went with the ashes into the ashpit, an equivalent of 22.5 was absorbed by the boiler, an equivalent of 10.4 went up the stack with the gases, and the equivalent of 5.9 was lost by radiation, incomplete combustion, and moisture in fuel. The largest loss was up the stack, due to large excess of air. The draft was 0.92 in. at the base of the stack, 0.06 in. in furnace, and 0.75 in. pressure in ashpit. The average thickness of fuel bed was 16 in. The fire was cleaned every hour. On account of the necessity of this frequent cleaning the average capacity fell below the rating of the boiler, although between the cleanings

of fire the capacity developed was above the rating. It was also due to this frequent cleaning that the stack losses were high.

The essential requirement for the economical burning of high-ash fuels is a continuous and automatic removal of ash from the furnace, so that the operation of the boiler need not be interfered with by frequent cleaning of fires.

B. S. MURPHY. The following notes are based on data from the Hudson & Manhattan R. R. Co., and especially from its Jersey City power station, which is an anthracite-burning steam-electric plant for an electric railway.

The boiler equipment consists of nine 900-hp. Babcock and Wilcox boilers, eight hand-fired and one equipped with a Coxe mechanical stoker.

TABLE 5 CALORIFIC VALUE OF COAL AS FIRED, B.T.U.
(Hudson and Manhattan R. R. Co. Station, Jersey City)

Year	Minimum	Average	Maximum
1911	11,230	11,523	11,750
1912	11,050	11,428	11,650
1913	11,450	11,741	12,000
1914	11,550	11,912	12,050
1915	11,550	11,712	11,900
1916	11,150	11,563	11,850
1917	10,850	11,170	11,350
1918 (4 mos.)	10,750	10,900	11,150

The fuel is anthracite of the small sizes. Our practice is to use Nos. 3 and 4 buckwheat mixed with bituminous and some No. 1 buckwheat, this latter with no soft coal added. All fuel, 115,000 tons of anthracite in 1917, came from the same contractor, and approximately all of it orginated from the same collieries, so that the combustible portion of the coal should be relatively the same. In Fig. 5, I have plotted the calorific value of the fuel by months in 1916 and 1917 and the first three months of 1918. In Table 5 are given the yearly averages and the maximum and minimum months during the year.

An ash analysis gives relative values for the ash content of a coal, but the true test is the proportionate amount of furnace refuse as compared with coal fired, for this figure takes into account the unconsumed carbon as well as the ash and other incombustibles, for the amount and kind of ash has a great bearing on the amount of

unconsumed carbon in the refuse, especially for hand firing. The average values of this for 1917 and 1918 are shown in Fig. 5.

From the foregoing it is evident that there has been a marked deterioration in our coal. The resultant economic effect I have

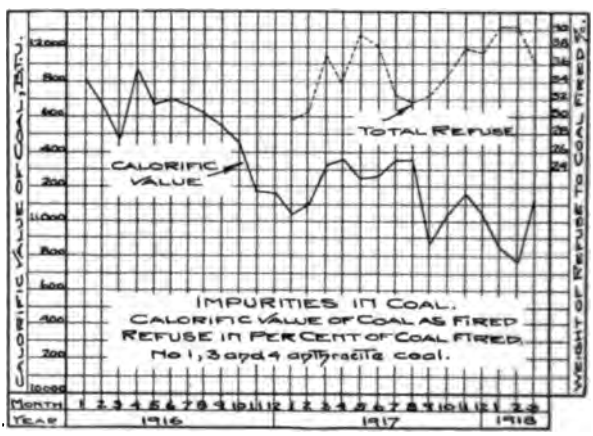

FIG. 5 FLUCTUATION IN HEATING VALUE AND REFUSE CONTENT OF COAL

shown in Fig. 6, which gives the average relation between the calorific value of the fuel as fired and the relative overall plant economy.

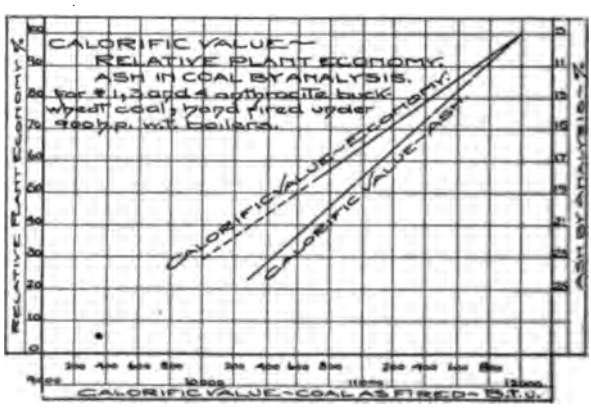

FIG. 6 INFLUENCE OF ASH CONTENT AND HEATING VALUE OF COAL ON PLANT ECONOMY

This has been plotted by the relative percentages, that is, assuming that the best coal we could expect would give a plant economy of 100 per cent, then a coal of 10,500 B.t.u. will show a loss of 53 per

cent or a relative economy of but 47 per cent; and extending the curve it becomes zero at about 9000 B.t.u., or the effective range is from 9000 to 12,000 B.t.u. In figuring the effect of a decrease in calorific value of the coal under consideration this range should be used and not the whole range down to zero B.t.u.

EFFECT OF HIGH ASH

Some of the poorer coals have ash by analysis as high as 24.45 per cent, with 10,294 B.t.u. calorific value of wet coal, while the better ones have only 9 per cent with 12,000 B.t.u., or a 15 per cent difference. This is plotted in Fig. 6, and though the curve is not extremely accurate, it would indicate that the limit for our coal was reached with about 30 per cent ash, this having a greater effect on the mechanical manipulation of the fires than on the lack of heat value.

The foregoing is based on hand-fired operation where the impurities content and kind of ash have a much greater influence than with stokers. The railroad load having marked morning and evening peaks is subjected to this much more than a plant with an average all-day load. The presence of impurities builds up the fires so rapidly that at times it is difficult to get through the service period without cleaning and necessitates the carrying of high ashpit pressures, at times 7 in. water gage, to burn the fires. Another noticeable feature that we have found with the No. 1 buckwheat is the formation of a light, puffy ash that builds up the fires so rapidly that they last only about three-quarters of an hour between cleanings, while an analysis of this same fuel shows but 16 to 17 per cent (gravimetrically) of ash, or a normal ash content, again showing that too much dependence cannot be placed on laboratory analysis for the effect on the fuel of the ash. As a rule, with anthracite the ash does not fuse into large, hard clinkers found with many kinds of bituminous coals; but even this has been noticed during the past winter, some of the clinkers being so large and so hard as to necessitate their removal through the fire doors instead of through the ash hopper.

Unconsumed Carbon in Refuse. In our station it is necessary to force the boilers during the service hours to 140 to 150 per cent rating. To do this with good firemen and good coal is not difficult, but when the impurities increase and the quality of men falls off it is extremely hard, one affecting the other. It is necessary with the good grades of No. 3 buckwheat to level fires about every eight minutes, and with the high impurities and uneven spreading it should

be done every three or four minutes. This is heavy, hot work; it is much easier to "bail" in coal, and the result is that the fire continues to build up because the ash and coked coal are covered with green coal until the fire becomes so heavy that it is impossible to get air through it. Cleaning then wastes a large amount of unconsumed carbon to the ashpit. The magnitude of this loss is shown in Table 6. With good fuel and well-trained, willing firemen this has been brought down to less than 20 per cent.

Summary. Summing up for the conditions as outlined for hand-fired boilers with the present grade of firemen available using Nos. 3 and 4 buckwheat coal with a relatively small percentage of bituminous, we find the following:

Calorific value, low limit, 10,200 B.t.u.; ash, high limit, 30 per cent, depending upon the behavior of the impurities

Effect on Plant Economy: An increase in consumption per kw-hr. of 53 per cent from 12,000 B.t.u. to 10,500 B.t.u.

TABLE 6 LOSS OF COMBUSTIBLE TO THE ASHPIT

Month — 1918	Unburned Carbon in the Refuse, Per Cent
January	44.10
February	39.24
March	40.39

coal. More coal is consumed, more coal is handled to the bunkers and to the fires and more refuse removed, increasing the unit cost of power

Effect on Personnel: Much hard work for firemen, with the result that the better men leave for easier work and poorer men are hired who use proportionately more coal and consequently make more work for themselves

Capacity: The capacity of a plant is limited by the small evaporation per pound of coal and the much shorter periods between cleanings

Remedy: If the amount of impurities and the correspondingly low calorific value cannot be remedied at the mines, where some of this should be eliminated, then the remedy at the fire room is the increasing of the bituminous-coal content in the mixture, the introduction of mechanical stokers and the training of firemen, if the men can be induced to stay long enough to be trained.

R. H. Kuss. Close observation supports the following views:

It is feasible to arrive at accurate conclusions on the subject of comparative performances in well-conducted plants only, since ash-variation effect is obscured when accompanied by slovenliness in operation.

The well-conducted plant employs its available draft intensity to advantage, meaning by this that the unit rate of capacity tends to be such as to demand strict attention to tightness of settings, baffle repairs, cleanliness, etc., resulting in a comparatively high rate of combustion where slovenly methods are not permissible.

A marked increase of ash content in the coal compels a reduction in the usual unit capacity rate due to greater grate-refuse resistance.

A corollary effect is to carry thinner active fuel beds, attended with unevenness of air distribution through like grate zones in order partially to overcome the disadvantages of lower capacity rates.

With a surplus of draft the ill effects of ash increases can readily be overcome, though plant practice as to firing methods must be modified to suit.

Where extra draft intensity is employed to overcome increased fuel-bed resistance due to extra ash, the necessity for setting tightness is increased.

The usual condition is that available draft intensity is deficient, and there is no choice but to operate at lower capacities, thereby causing plant standby fuel losses due to radiation, banking, blowdowns, soot blowing, combustible in the refuse, etc., to increase.

The writer customarily attributes one-half of one per cent as a justifiable decrease in efficiency for every one per cent increase in ash content, but believes this to be a fair figure only when the increase does not exceed 10 per cent of the total in ash content as revealed by a chemical analysis of the coal as fired.

A. S. Vincent. The building of which I have charge is the largest apartment house in the world, occupies a whole block, has 175 families and is thoroughly equipped with a high-class isolated plant. Our horsepower-hour outputs for 1916 and 1917 were almost identical, and yet in 1917 we consumed nearly 1000 tons more than we did in 1916, due only to the inferior grade of coal. In other words, the coal censumption in 1916 was about 7000 tons and in 1917 it was 8000 tons. This plant is equipped with everything an engineer could desire to enable him to keep plant records.

Our cost per boiler horsepower-hour in 1916, including all overhead charges, was $0.0114 and in 1917 was $0.017, due almost entirely to the excess coal used and at a cost of more than double the 1916 cost.

ALBERT A. CARY. In an investigation made in a number of the largest power houses in the East during the latter part of 1917 in the interest of fuel conservation and its bearing upon the transportation problem, I found that over 30 per cent of all transportation facilities carrying bituminous coal were burdened with unnecessary impurities. By unnecessary impurities I mean those above the normal ash which had been carried in the coal when the power houses were obtaining their coal under specifications defining the minimum B.t.u. per pound of coal and maximum ash content acceptable.

A. J. GERMAN.[1] Our experience with the impurities in coal has been interesting. We at first had trouble unloading the coal in that the foreign matter in the coal broke the crusher gears. More trouble is given when the coal comes into the automatic stokers. Then there is the further damage done to the furnace side walls and to the bridge walls. When about to unload coal we try to pick out the slate and rock on top of the car. We picked up pieces last winter as large as 4 ft. in length, 2 ft. in width and 5 in. in thickness. We picked out 9000 lb. of such material from three 45-ton carloads.

We use coal crushers with one set of rolls with bearings having spiral springs so that the rollers may give way and pass a too solid piece of material, such as rock and slate. Nevertheless we had considerable trouble with the breaking of the crusher. To avoid this we put in relays with an automatic overload release. This stopped the trouble, which may be considered to have been rather severe inasmuch as we broke six gears, three shafts and a number of bearings last winter. We use chain-grate stokers and have found that the great increase in the amount of dust in the coal allows a considerable quantity of the screenings to fall through the grate. We catch these in a hopper placed under the front of the stoker.

R. J. S. PIGOTT. In connection with the points brought up with regard to the effect of the increase of non-combustible material in coal, it is quite true that both the efficiency and capacity are seriously affected in hand-fired plants. It is found in underfeed-

[1] Waterbury, Conn.

stoker plants that with the proper operation only capacity is seriously affected. In two well-operated plants the efficiency of the boiler room has not been seriously affected by bad coal; but the capacity and maintenance of the equipment are affected. The increase of ash simply cuts down the B.t.u. that one can get into the furnace per sq. ft. of grate. The trouble is that many plants, due to the large increase in ash, have to run close to their safe margin of capacity, and, as it is difficult at this time to get additional apparatus, the trouble is a serious one. Therefore it is the hand-fired plant that suffers most seriously from this condition, and it is that plant to which the Fuel Administration will have to give the greatest amount of help.

P. W. THOMAS.[1] The incombustible portion of the coal limits the actual amount of heat contained in a pound of coal; its nature determines the percentage of contained heat which will be available for initial furnace temperature, and the components of ash have more bearing upon stoker design and furnace design than those of the combustible portion of the coal.

The following functions of the stoker are affected by the quantity and nature of the ash:

a Weight of coal fed per unit of heating service per hour
b The character of the fuel bed
c The coking time of the combustible coal
d The nature of the coke residue
e The proper diffusion of air admitted
f The actual mechanical performance of both moving- and stationary-stoker metal.

The design of the furnace is greatly affected by the nature of the ash and should be such as to avoid the following defects:

1 Impregnation of firebrick with slag formation
2 The building up of the smaller particles of fusible ash in the furnace, by which the throat is restricted.

Another item of consideration with respect to the ash, especially in horizontally baffled boilers, is that the velocity of the gases through the first pass must either be slow enough to deposit the ash particles in the combustion chamber or sufficiently strong to carry them toward the last pass to a lower temperature. If deposited in the first pass in a high temperature, they will build on the tubes and bottle the furnace.

[1] Fuel Engineer, Central Coal & Coke Co., Kansas City, Mo.

To our minds, then, the stoker should be selected after an investigation of the ash in the coal to be used. A typical analysis of fluxing ash is given below:

	Per Cent
Silica as oxide	43.50
Alumina	17.10
Ferric oxide	28.10
Calcium oxide	5.30
Magnesium oxide	0.75
Sulphur (sulphide occluded in CaO)	2.75
Carbon dioxide	trace
Carbon unburned	1.90
Alkali	trace
Moisture	trace
	99.40

The probable fluxing temperature of this ash is 2138 deg. fahr. (Cosgrove states that silica melts at 3227 deg. fahr. A silicate formed by the combination of FeO and SiO fuses at 2318 deg. fahr., and if part of this silica is replaced by 16 per cent CaO, the resulting iron-lime silicate will fuse at 2138 deg. fahr. The above ash, if considered from the standpoint of these three metals, contains 57 per cent silica, 37 per cent iron, and 16 per cent calcium.)

If the slag is allowed to accumulate in any receptacle such as a dump grate or ash pocket, its peculiar viscous nature will invariably cause trouble. Sooner or later the mechanism of the ash dump will clog, with a resultant shutdown for repairs to both ash pocket and grate.

If any of these coals is carried on a thick fire, an inversion or disturbance of the fuel bed will precipitate an ash run in the fuel bed proper. The slag is so heavy that I have known it to settle down into the tuyere boxes against a pressure of 5 in. of water, and within two hours close the entire air supply of the furnace.

Once the air is shut off, the condition becomes aggravated in the following manner: The pyrite FeS_2, instead of oxidizing to the relatively harmless ferrous oxide, reduces to ferrous sulphide, FeS, which has the same fluxing temperature as the ferrous lime silicate, 2138 deg. fahr., but when the FeS melts, it runs over the metal of the furnace and destroys it. Troughs and dead plates are warped and wasted. A run of molten iron sulphide through a grate of any type will in a few hours carry enough metal from the stoker to the ashpit to shut the boiler down.

T. A. MARSH. From such authentic data and investigations as have come to the writer's attention and observation with high-ash coals of Iowa, Texas, and Arkansas, particularly, there seems to be much to confirm the statement that there is a critical point in fuel value at a point where the non-combustible reaches 40 per cent. With furnace designs of the last five years it is not strictly true that such fuel is valueless, for some very creditable results are being obtained. Such fuels are being burned with 10 to 12 per cent CO_2 and with an ashpit loss of 5 to 7 per cent. Combustion rates of from 30 to 40 lb. per sq. ft. of grate surface per hour are common practice. The critical features, however, are as follows:

Low-heat-value, high-ash coals and lignites cost as much to mine as the better grades of fuel and in many districts it is advantageous to pay the increased cost of the better fuel in order to take advantage of the greater number of B.t.u. delivered to the boiler per unit cost by using superior fuel even at increased cost. Other advantages are high boiler ratings, less refuse to dispose of and more responsive boiler units.

This is therefore a commercial problem. If, on the other hand, the problem is isolated to one of burning high-ash or high-moisture coal, the writer would say that such fuels containing even as low as 7000 B.t.u. per lb. on a commercial basis are being burned in daily practice and in good quantities. The problem is simply one of furnace design and has been pretty thoroughly worked out for many such fuels. The type of furnace is, of course, dependent on the fuel and boiler to be served, which is a discussion aside from the topic at hand.

It is not generally known that lignites containing from 25 to 33 per cent of moisture are being burned in commercial quantities. In the present state of the art, little success has been attained with lignites having more than 33 per cent of moisture, but with lower-moisture lignites excellent results are being obtained.

These high-ash and high-moisture coals are burned on chain grates. Long arches are provided with special attention to the focusing of heat at the front to ignite the green fuel. The problem of ash and refuse disposal is absent as this type of stoker continually clears itself of ash, so that any furnace condition once definitely established can be maintained.

2 *To What Extent Is Fuel Oil Likely to be Used as a Substitute for Coal?*

ERNEST H. PEABODY. At the end of 1914 the total aggregate world output of oil since 1857 had reached the enormous total of about 5,500,000,000 bbl. (of 42 U. S. gal. each), of which the United States had produced about 60 per cent. By the end of 1916 this had risen to 6,478,944,229 bbl. In 1916, it is estimated, there were produced 460,639,407 bbl., of which the United States produced 300,767,158 bbl. or 65 per cent.

The data in Table 7 are from the preliminary report of the U. S. Geological Survey, and show that in the year 1917 the production

TABLE 7 FUEL-OIL PRODUCTION BY DISTRICTS IN 1916 AND 1917

Field	1916	1917
	Barrels	Barrels
Appalachian	23,009,455	24,600,000
Lima, Indiana	3,905,003	3,500,000
Illinois	17,714,235	15,900,000
Oklahoma-Kansas	115,809,792	147,000,000
Central and Northern Texas	9,303,005	11,000,000
North Louisiana	11,821,642	8,700,000
Gulf Coast	21,768,096	24,900,000
Rocky Mountain	6,476,289	9,200,000
California	90,951,936	97,000,000
Other Fields	7,705	.....
	300,767,158	341,800,000

in the United States had increased some 14 per cent over 1916, reaching the record-breaking total of nearly 342 million barrels.

FORTY PER CENT OF OIL AVAILABLE FOR FUEL PURPOSES

At least 40 per cent of all the crude oil produced will be available for fuel purposes. Nothwithstanding the great amount required for war purposes, particularly in the Navy and the rapidly increasing merchant marine, it is well worth asking whether or not oil fuel can be obtained for steam production on shore.

No definite statement can be made as to the availability of oil in any particular locality, especially under the existing conditions. At all times, in fact, this is purely a local question. In California, until recently our largest oil-producing state, and where no coal of importance is mined, oil will doubtless continue to displace coal. In Pennsylvania, on the other hand, there are great coal deposits,

while the oil produced is of a variety exceedingly valuable for refining purposes, so that coal as fuel holds decided superiority over oil except for special uses. In other portions of the country the balance may fall either way — as the production and the demand vary and as the transportation problem may determine. It would seem as if the Middle West should be well supplied with oil, as Oklahoma now produces more than one-fifth of all the oil in the world.

The Mexican production, while already very large (nearly forty million barrels in 1916), has been restricted on account of a deficient amount of tonnage to take the oil away. With adequate shipping facilities it is probable that the Mexican fields will constitute the natural source of oil-fuel supply for New England and the Atlantic states. There is one well alone in Mexico, the Cerro Azul, estimated to have flowed 263,000 bbl. a day, and it is interesting to speculate on what these fields may finally produce.

All indications point to the probability that there are enormous quantities of oil yet hidden in the earth's crust to be one day brought forth by the prospector.

CARE REQUIRED TO PREVENT WASTE OF OIL

A coal fire in the hands of a lazy or incompetent fireman may fall far below the desired standards of excellence; but it can only reach a certain minimum level of efficiency, and then it will go out. Coal is, in fact, of such a nature that it will quietly stand a certain definite loss in economic results, and then it will quit.

With oil there is no limit to the possible wastefulness that may exist. Give it poor burners, improper furnace conditions or not enough draft, and it will smoke and sputter and drip oil and waste itself away, but never give up. Give it too much air, a hundred times too much, and the fire will burn, the oil will disappear, the flame will be bright, there will be no smoke; but the waste may be so great that the boiler will not make enough steam to run the feed pump, even with the best furnace and burner arrangement.

It is approximately true that 1 lb. of oil equals 1½ lb. of coal in actual steam-making results. Roughly, this is equivalent to saying that 200 U. S. gal. of oil equals one ton (2240 lb.) of coal, or one ton of coal equals about 4½ bbl. of oil. A very handy rule, but like the rest only approximately correct, is this:

When the price of coal in dollars per ton (2240 lb.) is double the price of oil in cents per U. S. gallon, the cost of fuel for producing a certain boiler capacity will be the same for both fuels. Thus two-cent oil equals $4 coal, or four-cent oil equals $8 coal.

This rule takes into consideration the probable increased boiler efficiency obtainable with oil, but makes certain assumptions concerning the heat values of the two fuels and the weight of the oil per gallon which, while generally representative, may or may not be correct in any specific instance.

Generally speaking, one oil burner will be required for, say, 350 to 400 boiler hp., and one oil fireman can attend to about ten burners.

Reliable tests with oil fuel have shown that the boiler efficiency (i.e., the percentage of heat units in the oil which is actually absorbed by the steam leaving the boiler) may be as high as 83 to 84 per cent, although 78 to 80 per cent may be considered as good work, or even 75 per cent, in regular operating conditions. With coal fuel, while reports have been published by some pseudo-authorities showing over 80 per cent, the writer believes that such high results with coal can only be obtained with very large boiler units and the most efficient mechanical stokers. Certain it is that in hand-fired plants 75 per cent is about the maximum, while 65 per cent may be considered very good average work.

The advantage possessed by oil in respect to increased efficiency is due primarily to the small amount of air required for complete combustion in excess of the theoretical amount. This may be reduced to 10 per cent with oil, while the best tests with coal, hand-fired, show about 50 per cent, and good everyday working conditions run as high as 80 or 100 per cent.

MAINTENANCE LESS WITH OIL THAN WITH COAL

Maintenance charges are decidedly less than with coal. It is true that higher furnace temperatures with oil as a rule require a better quality of firebrick, and danger may result to boiler heating surface with improper furnace arrangements and burners. These points are easily cared for.

The theory of burning oil is different and radically distinct from that controlling the burning of solid fuel. Pulverized coal of course in some respects closely approaches the character of burning oil, but coal fired by hand or by stokers remains substantially at rest during combustion, and the air is brought to it. In the case of oil, the fuel is moving and the air moves with it.

In varying the rate of combustion of coal, the amount and velocity of the air through the fuel bed are altered — the intensity of the draft is increased or decreased. In the case of oil, the amount of fuel itself and the rate at which it enters the furnace must be varied.

and the amount of air entering with it must be increased or decreased to preserve the proper ratio.

The lighting of an oil fire is a simple process. The oil pump is started to give the necessary oil pressure at the burners. The draft is opened to provide sufficient air for combustion. A lighted torch is then placed directly under the burner tip, and the oil is then turned on. If the oil is at the proper temperature and the atomizer is working properly, the spray at once bursts into flame. *The spray must never be started without first placing a lighted torch beneath it;* i.e., no oil must be injected into a "dark furnace," for if it is, an explosive mixture may be formed in the furnace which will cause damage if ignited.

SELECTION OF TYPE OF BURNER

There is little or no difference in the action of compressed air and steam in atomizing oil as far as boiler work is concerned, and if the air is compressed to over 30 lb. per sq. in. there is no special difference in the design of the burner itself.

So far as the steam-boiler furnace is concerned, however, the prospective user of oil may forget the air atomizer, the one instance in which its use might be considered being that in which the saving of fresh water (consumed by the steam atomizer) is a matter of importance. And in this case a mechanical atomizer will probably do the work effectively, and will be preferred.

As between the claims of the steam atomizer vs. the mechanical atomizer, the issue is not as clear-cut. On board ship, except in the case of harbor vessels or those making port every day, the steam atomizer has given way to the mechanical atomizer, where the saving in fresh water for the boiler makes the use of the latter type practically imperative.

There is practically nothing to choose between the two types in operating results under equivalent conditions. The steam atomizer is, however, more flexible, i.e., the individual burner has a greater range in capacity; it costs less to install, notwithstanding that it requires two lines of pipe (oil and steam), whereas the mechanical uses only one, that for the oil. It is more readily applied to a coal-burning furnace, and conversely the furnace is more quickly converted back again to coal. It requires a lower oil pressure and not so high a temperature for viscous oils. It will also, in general, require less draft to operate. Furthermore, where special arrangements of burners are required, as in the case of the so-called "back-

shot" burner (placed at the rear of the furnace), the steam atomizer is susceptible of a wide range in design which has been found useful.

Thus, while the steam atomizer has many advantages, the mechanical atomizer gives excellent results also, and it will require actual comparative tests to determine finally their relative value in stationary boiler plants.

OIL PRESSURE AND TEMPERATURE

For steam (or air) atomizing burners, oil pressures of 25 to 50 lb. at the pumps are adequate, and under certain conditions even less pressures. Overhead tanks a few feet above the burners, feeding the oil by gravity, have been employed, but this is inadvisable on account of danger of fire, and pumps are usually employed. Mechanical burners require pressures of 50 to 250 lb. at the burner tip, 200 lb. being a favorite pressure for the designer. The wide range of pressure is useful in adjusting the burner capacity.

A steady oil pressure is a necessity for oil burners, a vital necessity for mechanical burners. Therefore large air chambers on the oil line are needed if the usual duplex reciprocating pump is used. Rotary pumps are being introduced in the Navy, and recently the screw pump has come into vogue. These pumps give a steady pressure oil with of little or no air cushioning, and the screw pump, particularly, seems to possess great possibilities for this work.

The matter of heating the oil is rather of a mechanical nature, as its importance bears on the viscosity of the oil rather than on any thermal advantage. Steam atomizers will handle more viscous oil than the mechanical type, therefore steam heaters using exhaust steam from the pumps and capable of heating the oil to 100 deg. to 125 deg. fahr. are usually satisfactory. The mechanical burner requires that the viscosity of the oil be reduced to 8 to 10 deg. Engler to spray properly, and this means that the oil (according to its viscosity) must be heated to 120 deg. to 280 deg. fahr. The latter temperature is required for heavy viscous oils that are appearing on the market to a greater and greater extent. In a mechanical-burner installation it is evident that the oil heater is a most essential part of the equipment.

IMPORTANCE OF AIR REGULATION

To a certain extent the amount of air being delivered to an oil fire is indicated by the color of the flame, a very bright, intense white (so desirable with coal) usually indicating that too much air is

being used, with a resulting loss in efficiency. Judging the fire by the flame, however, is only approximate; and it is better to resort to the simple device of diminishing the air supply until a light brown haze appears at the top of the chimney. This is preferable to a clear stack, as the latter gives no indication of excess air. The light haze is not at all objectionable but represents good conditions, provided — and this is a most important point — the smoke which produces the haze does not come from one or two burners only, while all the rest are working with oil. Complete combustion in the furnace (that is, combustion in which all the carbon is burned to CO_2 and no CO is present) will give an analysis with coal in which the CO_2 content, plus the free-oxygen content, will add up considerably higher in amount than an analysis of the products of similarly complete combustion of oil. The same percentage of CO_2 in the gas sample from coal indicates a much greater excess of air over that theoretically required than when oil is being burned. However, complete combustion of oil can be secured with a much lower amount of excess air than coal fuel; and it happens, therefore, that 14 per cent CO_2 in both cases represents the same satisfactory conditions in the furnace with both fuels.

The amount of air theoretically required for the complete combustion of 1 lb. of fuel oil of course varies with the composition of the oil, but it may be considered that about 14 lb. or 183 cu. ft. at 60 deg. fahr. represents the average.

BOILER FURNACE FOR OIL FUEL

In oil burning, "furnace volume" possesses a function similar to that of "grate area" in burning coal fuel. The rate of combustion of oil per cubic foot of furnace volume may be increased or decreased according to the intensity of the draft. A large furnace is necessary, therefore, if the draft is low, and the furnace can be made smaller if the draft is increased. This effect of furnace volume on the rate of oil combustion is often ignored or misunderstood; but it is of prime importance.

A high furnace temperature promotes the combustion of oil Owing to the less quantity of excess air, oil furnaces are usually higher in temperature than those burning coal, so that good-quality firebrick with a fusing point at least 3000 deg. fahr. should be used. Notwithstanding the higher temperature, if the burners are set and operate properly so that no flame impinges on the wall and no hard carbon is deposited, the wear and tear should not be great.

W. N. Best. The direct answer to this query is: First, in whatever equipment oil as a fuel is found to be cheaper than coal; second, whenever by its use an increased output is secured; third, wherever a superior quality of metal is produced; fourth, to safeguard against shutdowns in power plants through shortage of other fuels; and fifth, to carry peak loads in power plants.

We will first consider oil in power plants. If the coal used has a calorific value of 14,000 B.t.u. per lb. (good bituminous coal) it requires 147 gal. of oil to represent a long ton of coal (2240 lb.), the oil having a calorific value of 19,000 B.t.u. and weighing 7.5 lb. per gal. With oil at 5 cents per gal., this would be equivalent to coal at $7.35 per ton delivered in the coal bin. The larger the power plant, the more attractive is oil fuel, owing to the fact that one man can fire and water-tend twelve 300-hp. boilers. There are no ashes to handle and cart away. Of course the saving on all labor such as extra firemen and ash handling will vary in accordance with the number and size of boilers in the plant. I only mention this as a concrete illustration as to how an engineer can calculate the cost of the two fuels, so that any one can definitely determine if oil is attractive or not. The data used have been compiled from hundreds of tests.

In the eastern part of the United States oil as a fuel is rarely found to be as cheap as coal when used exclusively as a fuel in boilers; but last winter's experiences fully demonstrate the necessity of having coal-fired power plants equipped with oil as an emergency fuel owing to the uncertainty of the coal supply and also to the delay in delivery occasioned by the shortage of coal cars. It is the writer's opinion that no power plant today is safe without apparatus for the use of oil as an emergency fuel. Also, oil may be used as an emergency fuel to carry peak loads on either hand-fired or stoker-fired boilers. The liquid-fuel-injecting apparatus may be placed in the side wall of the boiler, midway between the bridge wall and front-end setting, or may be placed in the front-end setting and will not interfere with the fireman or stoker. A lever is used to operate the slide gate which admits the air to support combustion independent of the air admitted through grates or stokers; thus, if it is desired to operate the oil burner at 15 per cent of its capacity, the gate is only opened sufficiently to admit just enough air for the perfect combustion of that amount of fuel in combination with the coal. It can be so operated that no superfluous air is admitted into the firebox by simply moving the lever to any position required. As

soon as the supply of coal is entirely exhausted, the grates or stokers can be covered with cinders and oil burned exclusively. When a supply of coal is again secured, the cinders or ashes can be removed, the burner shut off and the air gate closed while only coal is again burned.

There are thousands of boilers in power plants and in gas works where to carry peak loads oil or tar is burned in combination with coal, breeze, etc. Also in power plants where bagasse is used as a fuel often oil is necessary to aid that fuel in obtaining the full rating of the boiler. Oil is an ideal fuel for this purpose, for by its use one can control and maintain the steam pressure as desired. It ordinarily requires 3 gal. of oil to each ton of bagasse burned.

I believe all marine boilers now burning coal should be equipped with oil as an emergency fuel. Especially should this fuel be used in the time of war, for by its use in combination with coal the boilers can be operated at 200 per cent overload in a few minutes, thereby increasing the speed of the vessel to its maximum.

In forging plants oil should be used as fuel, for thereby the manufacturer secures the maximum output and a better quality of metal. In this practice 80 gal. of oil are equivalent to a ton of good coal.

In heat-treating furnaces (low temperatures) 72 gal. of oil are required to represent a ton of coal of the calorific value referred to. Since it is true that steel is only as valuable as it is heat-treated, oil is superior to coal, for by its use in modern furnaces any temperature required can be attained and maintained at the will of the operator, and an even distribution of heat obtained over the entire charging space of furnace.

In foundry practice oil is an incomparable fuel for core ovens, and in steel foundries for mold-drying ovens, etc.

In chemical plants where accuracy of temperatures is very important, especially in the manufacture of dyes, oil fuel is a necessity.

In welding flues 58 gal. of oil represent a ton of coal (all coal and oil referred to here have the same calorific value). This is due to the fact that it is necessary to coke a coal fire before welding two pieces of metal together, and in this process of coking the coal all the volatile gases are wasted.

Owing to the superior qualities of oil, it belongs to that portion of the manufacturing world having forging and heat-treating shops, foundries melting various kinds of metals, and power plants for which an emergency fuel must be provided. I am confident that

when the war is over the nation having control of the most oil wells will be the largest manufacturer in the world; and if Germany controls the oil fields of Roumania and the Baku fields of Russia, our country's greatest competitor in the manufacturing world will be Germany, although we (the United States) now contribute 62 per cent of the world's production of crude oil. We must conserve this fuel and only use it where it can best serve the nation.

R. J. S. PIGOTT. One very important point militating against the substitution of fuel oil for coal (even if a supply were obtainable, which it is not), is the relative price of fuel oil and coal per million B.t.u. In all but the most favored localities, coal is about one-half, or less, the cost of fuel oil per million B.t.u. For instance, at Bridgeport, in 1915, coal was $4 a ton (14,250 B.t.u.) and oil 4 cents per gal. (19,000 B.t.u.); the relative cost was 12.65 cents per million B.t.u. for coal and 29 cents per million B.t.u. for oil. Any one contemplating the substitution of oil for coal would be faced with a doubled cost of steam production under such circumstances. The saving in labor due to elimination of coal and ash handling is insignificant. The difference in efficiency is now next to nothing, since the development of the underfeed stoker has put the coal-fired boiler practically on a par at all points with oil.

One very large source of waste, and an immense opportunity for saving, lies in our industrial heating processes. We have vast amounts of coal, oil and gas used in factory processes for heat-treating, annealing, pit fires, forge furnaces, etc., in nearly all of which cold work is introduced directly into an intensely hot chamber under direct flame, and no attempt whatsoever made to use the heat in the flue gases for preheating the work.

In connection with the writer's work at the Remington Company, we tested several types of oil-fired forge furnaces, as well as gas-fired brazing and other small-operation furnaces, finding the efficiency between 10 per cent and 15 per cent. In some cases, surface-combustion or semi-surface-combustion furnaces of our own design were substituted for Bunsen-flame types, cutting down gas to one-third, and in two cases to one-fifth, the former amounts. We should by all means employ preheating methods in our shop operations, making use of the familiar countercurrent principle so universally adopted in such heat-transfer apparatus as condensers, feed heaters and boilers. There is no question but that we could at least double the present poor efficiency of our usual primitive shop

furnace. At one of the large brass mills, conveyor furnaces have been developed that have practically doubled the heat efficiency.

Referring to the coal situation, Mr. Pigott said that the admirable work of Mr. Potter and Mr. Cole in Pennsylvania should have the hearty support of the Society, since it was a method of curing the cause, not the effect, — which eased the situation both from the coal burner's point of view and that of the transportation company. He therefore offered the following resolution, which was unanimously adopted:

WHEREAS, A large proportion of the shortage of fuel is due to the reduction of capacity and efficiency occasioned by the increase in non-combustible impurities in the coal as furnished from the mines, due chiefly to negligence on the part of the operators; and to the consequent increase in tonnage hauled for a given total heating-value; and

WHEREAS, Mr. William Potter, Fuel Administrator of Pennsylvania, has taken effective steps to force the proper cleaning of coal by establishing inspection at the mines, standards of quality and punishment for infraction; be it

Resolved, That the members in attendance at the Spring Meeting of The American Society of Mechanical Engineers indorse and support the action of the above-mentioned Fuel Administrator of Pennsylvania.

C. H. DELANY. To engineers on the Pacific Coast, where fuel oil has for many years been the only fuel available, the problem at present is what fuel can be substituted for fuel oil, rather than to what extent can fuel oil be substituted for coal.

During the past two years the price of fuel oil on the Pacific Coast has almost trebled, and in the Northwest its use has practically ceased, other fuels being substituted for it.

In California, where there is practically no coal available, the use of fuel oil still continues, but as the consumption at present is considerably greater than the production, it is questionable how long its use can be continued without restrictions.

OIL-FUEL SHORTAGE WILL GROW MORE ACUTE

The situation will shortly grow worse on account of the immense quantities of fuel oil required for the Navy, especially for the large number of destroyers that are now being built. It seems, therefore, that unless there is a considerable increase in the production of fuel oil, it is useless to discuss the possibility of its being substituted for coal; however, there is always a possibility of new oil fields being opened up.

In Table 8 a comparison is given of fuel oil with coal of heating values varying from 10,000 to 15,000 B.t.u. per lb. The heating value of the oil is given as 18,500 B.t.u. per lb., which is a fair average value for California oil, the variations from this value being small. It is well known that with good grades of semi-bituminous coal better boiler efficiency can be obtained than with the low-grade western coals, and to make this comparison fairly correct for the different grades of coal, an efficiency of 60 per cent has been assumed for coal having 10,000 B.t.u. per lb., and 75 per cent for coal having 15,000 B.t.u. per lb., with intermediate values for the coals that lie between these extremes. As the heating value of coal is usually given on the basis of dry coal, and as coal when purchased invariably contains a considerable proportion of moisture, it has been

TABLE 8 COMPARISON OF FUEL OIL WITH COAL OF VARIOUS HEATING VALUES

(Coal containing 6 per cent moisture)

	Coal						Oil
B.t.u. per lb. dry fuel	10,000	11,000	12,000	13,000	14,000	15,000	18,500
Boiler efficiency, per cent	60	63	66	69	72	75	78
Dry fuel per boiler hp., lb.	5.58	4.82	4.22	3.73	3.32	2.97	2.32
Fuel as fired per boiler hp., lb.	5.94	5.13	4.49	3.97	3.53	3.16	2.34
Coal equivalent to 1 bbl. oil (42 gal.), lb.	851	737	645	570	506	454	.....
Price of 1 ton (2000 lb.) of coal equivalent to oil at $2 per bbl., dollars	4.70	5.43	6.20	7.03	7.92	8.82	.....
Price of 1 bbl. of oil equivalent to coal at $5 per ton, dollars	2.13	1.84	1.61	1.42	1.26	1.13	.....

assumed that the coals considered in this comparison contain 6 per cent moisture. In the case of fuel oil the water content does not usually exceed 1 per cent, and this value has therefore been used in the comparison.

The comparison given here considers only the actual value of the fuel itself. An oil-fired plant is considerably cheaper to build than a coal-fired plant, due to the lack of coal-handling apparatus, mechanical stokers, etc.; furthermore the labor in the oil-fired plant is much less than in a coal-fired plant, and consequently the actual comparison for any particular plant will be somewhat more favorable to oil than is shown in Table 8.

Fig. 7, which extends the information contained in the table to other prices of coal and oil, will serve as a rough guide for those

who contemplate changing from one fuel to the other. The efficiency of 78 per cent for oil firing assumed in these calculations can be readily maintained in normal service provided proper attention is paid to the furnace design and the regulation of the fires.

AUTOMATIC REGULATION OF FIRE

One of the greatest advantages of the use of oil as fuel is that it is possible to regulate the firing entirely automatically. It is well known that in the modern power plant the efficiency obtained depends very largely on the personal element in the fireroom. This personal element has been largely eliminated in the engine room by making automatic the regulation of modern prime movers. In the

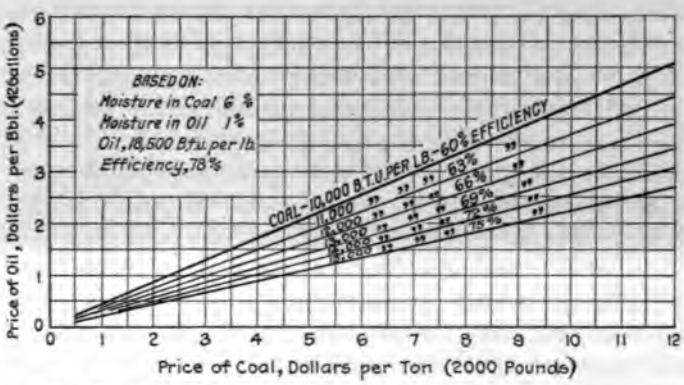

FIG. 7 COMPARISON OF FUEL OIL WITH COAL OF VARIOUS HEATING VALUES

fireroom, however, it is customary to depend entirely on the judgment of the fireman to regulate the supply of air that will insure commercially perfect combustion and give the highest efficiency. By making this regulation automatic the method of operating the plant changes, for it is then only necessary to adjust the fires at the start, and if the automatic regulator is reliable, it will keep the fires in proper adjustment for all loads.

Automatic regulators are now on the market for oil burning which regulate the quantity of oil, the quantity of atomizing steam and the quantity of air required for combustion. While the main advantage of the automatic device is that it insures the boiler operating at maximum efficiency at all times, it also has the advantage of causing considerable saving in labor.

This advantage will be especially true in the case of small isolated plants where the firing is of poor quality and where the cost of labor is large in proportion to the quantity of fuel burned, and it is in these small plants scattered throughout the country that the greatest benefit would be derived if it were possible to substitute fuel oil for coal.

W. G. WILLIAMS. Prior to 1915 fuel oil offered coal keen competition in many parts of the country, but war conditions have placed a different aspect on the situation, and it is safe to say that the present conditions are far more likely to prevail after peace is declared than that pre-war conditions will obtain.

The requirements for petroleum products of the lower end points necessarily keep pace with the growth of the internal-combustion engine; that the production of crude petroleum has not kept pace is evidenced by the reduction of crude in storage. In 1916 there were 162,000,000 bbl. of crude in storage, and at the present rate of reduction this reserve will be exhausted in 1919.

Certain localities and requirements make the use of other than liquid fuel practically out of the question. On the Pacific Coast oil will be used to the exclusion of coal until one of two things occurs — production of crude petroleum falls off, or a method is discovered of converting the output of crude into gasoline. In the marine industry oil is practically the ideal fuel, and with the enormous increase in shipbuilding in the United States it is not too conservative to say that our fuel-oil output is destined for almost exclusive use on shipboard.

It is true that the maximum output of the Mexican fields is still an unknown quantity, and that the known oil fields are only a small part of those yet to be discovered, but against this must be considered the proved life of the fields, and the efforts to convert crude petroleum into gasoline exclusively.

With the gigantic strides that are being made in the application of internal-combustion engines for motive power, the effort to produce a corresponding increase in the fuel for these engines is taking two forms, namely, an increase in production of crude, and of gasoline from the crude. How little these efforts are being rewarded is shown by the decrease in production in the Kansas, Oklahoma, and Texas fields of 82,000 bbl. per day since last October, and the practical failure of the "cracking" processes so far developed.

Any calculations based on the use of petroleum as fuel are, how-

ever, rendered valueless by the fact that any hour of any day may witness the development of a new oil field which will produce petroleum in such quantities that its use as fuel would largely supplant coal. The exhaustion of known fields is no bar to the discovery of new and larger producing areas, and I believe it is a wise engineer who keeps this possibility in mind, just as he would the ultimate development of a small steam plant into one of a size to eventually accommodate automatic coal-handling and -firing equipment, and I believe this is particularly applicable to those of us doing business west of Pittsburgh.

C. W. Koiner. No relief can be looked for in the East from the substitution of fuel oil for coal except for ocean-going vessels and, possibly, to a limited extent, for the reason that this oil would have to come from the southern and Mexican fields and the conditions in Mexico are so chaotic that the full supply of oil that these fields are capable of putting out cannot be depended upon.

Practically all hydroelectric plants in California have been linked together from the southern to the northern part, a distance of approximately 800 miles, with a view of eliminating oil-burning plants wherever possible. The oil reserve in California has, during the months of January, February and March, been drawn on to the extent of 1,655,000 bbl. The month of April, however, shows a little improvement. The production has been increased and the lack of shipping facilities for carrying the oil to its destination has prevented the reserve being depleted as much as during the past year.

FUTURE SUPPLY FROM VAST OIL-SHALE DEPOSITS

Guy Elliott Mitchell of the United States Geological Survey, in an article in the *National Geographic Magazine* for February, 1918, stated that the total production of petroleum in the United States up to 1918 was 4,255,000,000 bbl. In regard to future production, he estimates that the total amount in the ground, some of which lies very deep, is about 7,000,000,000 bbl. This is small compared with the quantity of oil that can be extracted from our oil-shale deposits. He tells us that American deposits of oil shale will supply enormous quantities of oil in the future. It is estimated that 20,000,000,000 bbl. can be obtained from the oil shale in Colorado alone; that certain ranges of mountains in which these deposits are located carry thick beds of rock that yield 30 to 100 gal. to the ton.

The shale deposits of Indiana are estimated to carry 100,000,000,000 bbl. of oil. There are also deposits in Wyoming, Nevada, Illinois, Kentucky, Ohio, Pennsylvania, Tennessee and West Virginia; therefore our oil supply for the future is assured, even though we fail to develop additional oil territory other than the shale deposits.

VICTOR J. AZBE. Fuel oil is the ideal fuel for boiler purposes. It gives high boiler efficiency, high boiler capacity, rapid regulation, low cost of handling, low cost of firing with hardly any disadvantages, but it should not be burned in localities with a coal mine only 30 miles off. In the southern states, especially Texas, plants are equipping to burn lignite in preference to the present expensive fuel oil, and those which are not should be made to do so.

Lignite is the best fuel to be burned in territory where available. Very good results can be obtained with it and 12 per cent CO_2 maintained without difficulty. With intelligent firemen in charge as high boiler efficiency will be obtained with lignite as with coal, and it has not been unusual for the writer to obtain 65 per cent combined efficiency with ordinary return tubular hand-fired boilers; and with proper design boilers can be forced far beyond their rating with lignite.

The value of wood as fuel also is not realized, and as an example I will mention a certain plant in Louisiana that burned oil for years at 80 cents per barrel. All at once the cost of oil increased to $1.40 and they began burning wood and during the next fiscal year the cost of fuel per unit of output was far less than with oil at 80 cents. To think of this and then of the enormous quantities of wood wasted throughout Mississippi and Louisiana and other states makes a man realize how unadaptable we are.

H. A. BARRE. Oil is practically the only fuel used for power purposes in California, except a small amount of natural gas.

Originally it was burned as it came from the wells, but of recent years the crude oil is all topped for the lighter constituents, and the residual only, having a gravity of 14 deg. to 18 deg. B., used for boiler fuel. The unit of measurement is the barrel of 42 gal. weighing about 335 lb. and containing from 6,000,000 to 6,200,000 B.t.u. Compared with 12,000-B.t.u. coal, one ton of 2000 lb. equals nearly four barrels of oil.

Before the war the price for favorable delivery points, such as tidewater and pipe-line terminals, was 60 to 70 cents, equal to $2.40

to $2.80 coal. At present the market is about $1.45 per barrel, equivalent to $5.80 coal per short ton.

These figures are not entirely just as a comparison, since the expense to store and fire oil is much less than for the corresponding thermal equivalent of coal. There are no ashes to dispose of, and ease of control in firing admits of higher operating plant efficiencies. The same amount of investment will therefore produce higher thermal efficiencies than with coal.

The arrangement of the furnace is more important than the type of burner used.

The oil is usually atomized by steam. The resultant spray is burned by mixing with the proper quantity of air and distributed evenly throughout the firebox without directly striking the surfaces of the tubes and furnace walls, but also without permitting the occurrence of blank spaces which might admit a surplus of air.

There are several types of burners, between which there is little to choose. Any of them that will properly atomize the oil and distribute the flame are satisfactory. The two extremes of the scale of desirability are, on the one hand, the burner which, by the use of a slight excess of atomizing steam, gives steady and reliable service, and, on the other hand, the one where the steam passages are reduced to just the amount necessary for atomization, but which must be watched a trifle more carefully on account of plugging up at times with dirt or carbonized oil.

The steam consumption of the former type is not over 4 per cent of the boiler output, and of the latter slightly less.

The most important instrument for oil burning is a window in the roof, through which the boiler-room engineer can see the top of the stack. Smoke, of course, is always a loss, and when firing up cold boilers cannot be avoided. A more serious loss, however, is excess of air, and this can occur with a perfectly clear stack. The best firing will be done by increasing the amount of air until the smoke stops and then cutting it down slowly until a slight haze of smoke shows.

In the larger plants, of course, more scientific methods are available. Steam-flow meters, venturi meters on unit groups of boilers, and the customary stack instruments are used and pay better returns than perhaps any other part of the investment, provided always that the information obtained from them is used for the immediate correction of any deviation from normal conditions.

Two large and comparatively modern plants have been for some

years under the writer's observation. One of these is of 40,000 kw. capacity, having three 5000-kw. engine-type units, installed in 1906, which are seldom used, and two 15,000-kva. turbines installed in 1910 and 1911. The other is of 47,000 kw. capacity, having one 12,000-kw., one 15,000-kw., and one 20,000-kw. turbine. This is much the better plant.

TABLE 9 OPERATING CONDITIONS WITH FUEL OIL

Year.	40,000-Kw. Plant			47,000-Kw. Plant		
	Kilowatt-Hours Output	Bbl. of Fuel Oil	Kilowatt-Hours per Bbl.	Kilowatt-Hours Output	Bbl. of Fuel Oil	Kilowatt-Hours per Bbl.
1911....	126,377,000	574,178	220.03	.....	.....	.....
1912....	150,801,000	732,444	206.00	50,300,000	240,537	209.0
1913....	163,015,000	756,652	215.44	94,046,000	439,454	214.0
1914....	18,588,000	161,190	115.30	74,812,000	347,008	215.7
1915....	5,274,000	88,576	59 50	77,556,000	328,749	236.0
1916....	3,785,000	81,783	46.30	45,360,000	218,225	207.5
1917....	4,930,000	83,692	58.80	133,528,000	562,177	238.0

These two plants are a part of a large interconnected system having a total capacity of nearly 200,000 kw., and run in conjunction with a number of water-power plants.

They serve three functions — (1) As a steam reserve for breakdown of lines and other plants; (2) To supply kilowatt-hours during the season of low water; (3) To care for increases in load until these

TABLE 10 BEST OPERATING RESULTS

Plant	Kilowatt-Hours per Bbl.	B.t.u. per Kilowatt-Hour	Per Cent Efficiency
40,000 kw.....	220	27,300	12.5
47,000 kw.....	240	25,000	13.65

reach sufficient magnitude to justify bringing in additional water power. The annual loads and load factors are therefore of an erratic nature.

The operating conditions for several years past are shown in Table 9.

It will be seen that the best annual operating results have been approximately as shown in Table 10.

In both these tables the results are net after accounting for station auxiliaries; that is, the measurements are oil delivered to the stations and kilowatt-hours output at the station feeders.

Some oil-burning plants having a high load factor have recently been put into operation in Arizona, operating at about 19,000 B.t.u. per kw-hr., or nearly 18 per cent efficiency.

In these two plants a 600-hp. B. & W. or Stirling boiler will carry with auxiliaries about 1000 to 1100 kw. of station output.

3 *How Can Soft Coal Be Burned Without Smoke in Marine Boilers?*

ALBERT A. CARY. The question submitted in this topical discussion is very simple and direct, and equally direct answers might be given by stating: suppress the fires in the furnace by firing in such small quantities as to prevent the emission of smoke; or, secure *complete* combustion in the furnaces and combustion chambers. The first-named method, of course, must result in a serious loss in the vessel's speed. The second method gives the only wholly rational solution of the trouble.

The average types of marine boilers with their present form of attached furnaces make it well-nigh impossible to secure complete combustion within the furnace in such a way as to suppress smoke without sacrificing efficiency. On the other hand, it is possible to make rational changes in the steam-generating equipments for *new* ships so as not only to suppress the smoke nuisance, but to carry vessels through the danger zone at their highest speed.

To accomplish this highly desirable end by working along the lines of the latest successful developments in land practice, we shall probably require 4 ft. more headroom, in which to place the boilers, but even should 5 ft. be demanded, the tremendous advantage gained would far offset any objections that could be raised to this innovation in the marine-boiler practice of the past.

EXAMPLE OF A STATIONARY INSTALLATION APPLICABLE TO MARINE PRACTICE

To illustrate, I will refer to an equipment for stationary boilers in which I have been interested from a purely professional standpoint, and which can be practically adapted to marine service in new vessels to secure high rates of coal consumption without producing smoke.

Eighteen stokers have been operating 500-hp. boilers 24 hours per day continuously for two years, at 50 per cent above their rating,

with average grades of eastern bituminous coal of no better quality than is used by transatlantic ships. They have been continuously burning from 42 to 45 lb. of coal per sq. ft. of grate per hour, with a clean, smokeless chimney and have shown an easy forcing capacity when over 60 lb. of this eastern bituminous coal is burned per hour per sq. ft. of grate.

The coal is fed from the hopper to the fuel bed in a steady flow in such manner as to avoid the trouble usually following its coke formation and the troublesome caking, and then it is moved along the grate automatically so as to constantly drop its ash directly down to the grate surface where the cool entering air keeps the temperature of the ash below its fusing point, thereby avoiding the formation of obstructing clinker.

The resulting ash is dumped into an air-sealed pit where it is water-cooled and an automatic ash-removing device carries it forward into the front ashpit without disturbing the air seal and without disturbing the draft conditions of the furnace.

The deep fuel bed is always kept in an open porous condition over its entire surface like a huge sponge, thus requiring a light air-blast pressure, seldom exceeding 1 in. water pressure, and allowing each stoker to be operated with an individual disk fan (requiring but little power to operate) instead of the usual heavy steel-plate, forced-blast fan with its voluminous air ducts. The result is not only a saving in power required for operation but also a material saving in space requirements.

With the clinkering trouble in firebed, side and bridge walls thus avoided, hand cleaning of the firebed is almost entirely done away with while the firebed is easily kept level and of uniform thickness by an arrangement of the automatic feed device.

Adjustment of the rate of coal feed is quickly and easily changed (along with the speed of the fan), and thus, with the free-burning firebed conditions existing, a jump from low to high steaming capacity in the boiler is obtained in a very few minutes.

With such exceptional fuel-burning conditions under marine boilers, the production of smoke would be prevented by securing practically complete combustion in the furnace, and the highest steaming capacity of the boiler obtained to take the vessels through the danger zone at high speed.

With the coal supplied to the furnace by simple conveying apparatus and with ash delivered from the ashpit automatically by the stoker and conveyed overboard automatically, hand manipula-

tion can be almost entirely done away with and a happy solution secured of the present difficulty in getting the greatly needed expert firemen.

OSBORN MONNETT.[1] As to whether soft coal can be burned without smoke in marine boilers, there can be but one answer: Yes. As a purely engineering problem it is feasible. Of the methods tried for this work the underfeed principle has been best adapted. With this method the headroom and ashpit facilities may be cut to a minimum and the auxiliary machinery required is comparable to that ordinarily used for forced-draft hand-fired furnaces. Furthermore, this principle of burning soft coal is well adapted to the character of the load (variable speed, etc.), and handles to good advantage the class of coal customarily used for marine purposes on our eastern seaboard. Theoretically, all points are in its favor.

Moreover, considerable practical experience has been gained with underfeed stokers in marine work in the past ten years. A number of marine installations are operating successfully today, among which might be mentioned the following: Steamer *Sprague* — 6 Scotch marine boilers — 12 stokers; tug *Perfection* — 1 marine firebox boiler — 1 stoker; tug *Mollie Spencer* — 1 marine firebox boiler — 1 stoker; dredge *Wm. O'Connell* — 2 double-end Scotch marines — 8 stokers; steamer *Gamma* — 6 tubular boilers — 6 stokers; dredge *Hecla* — 2 Scotch marine boilers — 2 stokers; Ward Engineering Co. steamers — 2 Ward marine water boilers — 4 stokers; Holland-America Line steamer, *Frederick VIII* — 8 Yarrow boilers — 16 stokers.

These installations, all of the Jones underfeed type, cover a wide variation of marine service from dredges and river steamers to transatlantic liners, and all types of boilers, including Scotch marine, marine firebox and water-tube boilers, of both straight- and bent-tube varieties.

The problem is not so much a mechanical one as it is one of the human element. Put one man (fourth engineer) who is familiar with this type of equipment on duty on each watch and no difficulty need be experienced. The necessary men could be recruited from the large number of power plants in this country now using underfeeds.

As far as hand firing with Scotch marine boilers is concerned, experience has been discouraging. The writer once succeeded in

[1] American Radiator Company, Chicago.

operating smokelessly a steamer so equipped, without any apparatus, simply by charging alternate fires. It happened that the boilers, two in number, were equipped each with three corrugated furnaces, all discharging into a common combustion chamber. The volatile matter from the fresh fire was consumed by the hot gases from the other two fires. With two furnaces the results would have been less satisfactory, and with separate combustion chambers (a common construction) impossible.

The idea in hand-fired furnaces has been to mix the gases, after they pass the bridge wall and while they are at a high temperature, with an auxiliary supply of air, and so accomplish complete combustion. Experiments have been made in Chicago Harbor with brick arches, baffles and other constructions calculated to do this, but the small space available in the Scotch marine boiler has prevented satisfactory results. In fact, the writer's experience with forced draft, induced draft, special air admission, preheated air, panel doors, steam jets, induction tubes, stack blowers, hollow bridge walls, etc., has led to the conclusion, more strongly than ever, that some type of underfeed stoker is the logical answer to the Scotch marine boiler problem.

In water-tube boiler construction, such as has been adopted by the Emergency Fleet Corporation, there is more opportunity to do things and it is not unreasonable to hope that a satisfactory hand-fired furnace for these units will be developed.

H. B. Oatley. At or above the normal rate of operation, the burning of soft coal with the complete elimination of smoke, if not impossible, is an extremely difficult problem. A great deal, however, can be done to approach this desired state of perfection.

Conditions which will secure proper combustion may, of course, be provided on new ships and we are led to expect well-designed boilers, furnaces and uptakes on the ships now building. On existing vessels, however, unfavorable conditions may exist with respect to the proportions of air openings through the grates, volume of furnaces and combustion chambers, area for gases through fire tubes and around water tubes, and finally areas of uptake, breeching and stacks. The means for heating the air supply, in forced-draft installations, may have been inadequately proportioned. It is very desirable — in fact, it is imperative — to improve these conditions to the greatest extent possible. It is probable that to correct these conditions, so far as the boiler itself is concerned, would be prohibi-

tive on account of delay and expense in installing new boilers. Grates, uptakes and the air-admission channels, however, may be corrected in a short time and at a reasonable cost.

Steam economy is a big factor in the elimination of smoke, because it results in reduction in the amount of fuel used and reduction in the rate of combustion.

Improvement in marine steam plants, considering the present use of triple-expansion engines, turbines, feedwater heaters, well-lagged steam pipes, etc., presents fewer opportunities than in other lines. In the use of superheated steam, however, marine power plants in this country are considerably behind the merchant marine in other leading countries. There are opportunities for reducing the fuel used by upward of 12 per cent, and naturally a *greater* percentage reduction in the smoke produced. This is particularly applicable to existing ships as the necessary installations may be made at moderate cost during an overhauling. A reduction in the fuel used would make suitable many plants that have restricted areas through which the gases pass, and permit of greatly improved combustion.

For existing ships there is a greater reduction in smoke to be expected by the more economical use of steam, at least under present conditions, than by any other means.

M. C. M. Hatch. Soft coal can be burned without smoke in marine as in all other boilers and furnaces, up to the point at which the furnace volume becomes too small to allow for proper air-mixing and combustion space for the volatile hydrocarbons contained in the coal. This varies, of course, with designs, but the limits imposed by the unavoidable restrictions in designs for marine work make it most difficult to force high ratings from such boilers, under hand-fired conditions, without smoke.

Coal, in pulverized form, induces the desirable intimate mixture of gases and air very early in the process of combustion, and it has been shown, as it is logical to expect from the very nature of its burning, that less total air is needed per unit weight of fuel than with hand firing. In support of this it has been repeatedly shown, in locomotive and stationary practice, that smoky coals can be burned smokelessly at very much higher rates of combustion than possible under any other conditions. The logic of the case and the facts in other services all point to the conclusion that soft coal, in pulverized form, can be burned in marine-boiler furnaces at much

higher rates than will ever be possible to attain with hand firing, and that smoke will be eliminated or very materially reduced. To just what point the furnaces could be forced, in any individual instance, depends very largely on their fundamental design and volume, but in any case the smoke thrown would certainly be much reduced by the use of pulverized coal.

HENRY KREISINGER. Perhaps the best way of burning soft coal in marine boilers without smoke is to do away with hand-fired furnaces and install mechanical stokers or pulverized coal.

For smokeless combustion, two requirements are essential: First, the volatile matter must be distilled at a uniform rate; second, the distillation must take place in the presence of large amounts of free oxygen so that the volatile matter can be burned before the smoke is formed. These requirements are not satisfied in the hand-fired furnace. On the other hand, most of the mechanical stokers, as well as the powdered-coal furnaces, furnish means of satisfying these two requirements.

In the hand-fired furnace the distillation is rapid immediately after firing and most of the volatile matter is distilled during the first half of the firing cycle. It is difficult to supply enough air during this period of rapid distillation without having too high an excess of air after the distillation has been nearly completed, unless the air supply is varied in such a way that it is at all times nearly proportional to the amount of volatile matter that is being distilled. Such variation of air would require close attention on the part of the fireman and is hardly practicable aboard a ship where firemen are changed frequently.

In the hand-fired furnace the distillation of the volatile matter takes place in the absence of oxygen, and the volatile matter is broken down by heat into soot and light hydrocarbons. The fresh coal is placed on top of the fire and moves down toward the grate. The air is fed from below through the fuel bed in the opposite direction to that of the coal. Before the air reaches the distillation zone at the surface of the fire, all the oxygen is used up in burning the carbon in the lower layers of the fuel bed. The sooty smoke is formed at the surface of the fuel bed because there is no oxygen to burn the volatile combustible, and because the latter is subjected to high temperature; it is not formed by sudden cooling.

Most mechanical stokers feed the coal into the furnace at a uniform rate so that the volatile matter is distilled also at a uniform

rate. It is therefore comparatively easy to adjust a uniform supply of air to the volatile matter to insure its complete combustion without a too high excess of air.

Furthermore, with most of the mechanical stokers the air and the coal are fed into the furnace in the same direction, so that at the point where distillation takes place the air contains nearly 20 per cent oxygen. On account of this large percentage of free oxygen the combustion of the volatile matter proceeds to completion without deposition of soot.

What has been said about the mechanical stoker is true of the pulverized-coal burner. The coal and air are fed into the furnace together at a uniform rate so that the two can be easily adjusted to the proper proportion. The volatile matter is distilled from the small particles of coal while the latter are surrounded with an atmosphere containing nearly 20 per cent of oxygen.

With the pulverized coal a large part of the mixing of the combustible with the air can be done outside of the furnace. Thus the combustion space of the furnace needs to do only the burning and little mixing. Something similar to this is being done in the gasoline engine. Only the burning is done in the combustion chamber, the mixing being done in the carburetor. High temperature is of lesser importance. Complete combustion can be had in the gas-engine cylinder in spite of the fact that the walls of the combustion chamber are water-cooled.

Carrying on the mixing outside of the furnace deserves full consideration in the case of marine boilers, because the restriction of space on board ship makes large combustion chambers prohibitive.

HAYLETT O'NEILL.[1] For the past two months I have been running tests of marine boilers at New Haven, Conn., using pulverized coal and a fuel composed of pulverized coal and oil. We have been able to burn these fuels without smoke, and have obtained just as much speed and power as with the regular oil-burning equipment aboard this ship. The boilers are of the Normand express type, with a very small furnace particularly unsuited to such fuel as powdered coal. I believe that the future will see much work done in marine practice in the way of substituting pulverized coal for oil, inasmuch as the fuel in the form of coal will cost about one-half or even one-third what the oil will cost, with about the same cost of handling.

[1] 115 Broadway, New York, N. Y.

[On board the boat mentioned by Mr. O'Neill a mixture of powdered coal and fuel oil is used — 32 per cent of the mixture being coal, 95 per cent of which passes through a 200-mesh screen. The coal, by reason of a newly developed fixateur, remains suspended for many days without settling so seriously as to interfere with operation. The usual mechanical Navy burner is used without alteration. The volumetric heat value of the mixture is about the same as that of the straight oil with an average good coal because of the greater density of the coal. If this mixture of oil and coal proves to be successful, it would, of course, if widely applied, go a long way toward relieving the consumption burden now imposed on our fuel-oil resources. — EDITOR.]

JOHN S. SCHUMAKER. In the Assabet mills, Maynard, Mass., about twenty-one Manning type boilers were used to burn New River coal. The furnaces of these boilers have no firebrick, and, ordinarily, considerable smoke was formed in the combustion of the coal. It may be interesting to know that this trouble was practically eliminated by the introduction of air above the fire. The fire doors were at first left on the latch, that is, left open a trifle, and later, as a permanent arrangement, 5-in. openings were introduced in each door. These openings, when properly regulated, greatly reduced the smoke.

Under normal operating conditions insufficient air was supplied through the ashpit doors by reason of their being partly obstructed by the grate-shaking device. This deficient air supply resulted in uptake gases showing about 13½ per cent CO_2 and 3 to 4 per cent CO. The introduction of air over the fire compensated for the deficient under grate supply and made the uptake gases show 14 per cent CO_2 with only traces of CO, the smoke incidentally being greatly reduced.

4 *What Are the Possibilities in the Direction of the Utilization of Anthracite Wastes?*

JOHN E. MUHLFELD. The exclusion of almost one-half of the 48 states in the Union from participation in this year's anthracite-coal production, and a shortage of 25,000 to 50,000 men from the number normally engaged in the anthracite mining field, in combination with the lack of water and rail transportation facilities, establishes the immediate necessity for reclaiming and utilizing every ton of anthracite silt, slush and culm that is now being produced or which is stored above ground.

ANTHRACITE WASTE SHOULD BE CONSUMED AT THE MINES

As about one ton of anthracite coal is now consumed at the mine in the production of steam to mine each 8 or 9 tons produced, the logical use to which these waste sizes should be put is in the production of power, heat and light at the mines. By this procedure useful by-products of from 11,000 to 12,000 B.t.u. heat value per pound — which are now being wasted by diversion to streams, back filling into abandoned mines, or by dumping in culm banks, and which represent about 10 per cent of the total tonnage mined — can be made to release from 85 to 90 per cent of the commercial-size anthracite that is now being consumed for mine steam generation for use in locomotives and at industrial plants located nearest the points of production. In other words, in the production of 80,000,000 tons of domestic and steam anthracite during the current coal year, the reclamation and utilization of the silt, slush and culm by-product for mine-operation purposes would release about 8,000,000 additional tons of steam-size anthracite that could be diverted to commercial use and more than make up the shortage in supply.

It should be remembered that the only cost for this additional tonnage would be the means required for its reclamation and for its preparation and use, as the labor, material and plant for mining are now being employed in its production.

By pulverizing this by-product anthracite and burning it in suspension, as oil or gas is burned, it can be used for stationary-boiler purposes without the admixture of any other fuel, and easily produce from 100 to 150 per cent of the rated boiler capacity. For locomotives it can be utilized by mixing 60 per cent with 50 per cent of any gas or soft bituminous slack or screenings available, then pulverizing, and burning it in suspension.

BURNING ANTHRACITE IN SUSPENSION

The ideal means for preparing and disbursing this fuel would be to install preparation plants at the collieries, from which both locomotives and stationary power plants could be supplied, thereby relieving railway facilities, locomotives and cars otherwise required for its transportation. Such utilization would also avoid the use of cars and vessels for hauling fuel with a relatively high percentage of non-combustible. Every ton of anthracite to be shipped by rail or water for any considerable distance should have not more than 10 per cent of ash and impurities and be of the best quality possible to conserve the already overburdened transportation facilities.

Anthracite by-products can be reclaimed and utilized for what it now costs to place them on the dump or to pump them back into the mines, and by proper preparation and burning in suspension — as with oil or gas — there will be the additional power-plant advantages of reduction of man power, greater boiler capacity, better control of steam pressure, elimination of banked fires, decreased ash-pit handling, elimination of fire cleaning and of metal work in the furnace, better combustion, and lower fuel losses.

Furthermore, with the relatively low volatile nature of these waste by-products, which require a temperature of between 550 and 600 deg. fahr. to produce combustion, there will be no difficulty in handling or storing fuel after pulverizing in any manner desired from the standpoint of loss of heat value or spontaneous combustion.

At present the bituminous coal supply is only running at from 75 to 80 per cent of production, due largely to a shortage of from 10 to 15 per cent in the car supply. As the anthracite supply of commercial steam sizes is also inadequate, unless some means is immediately adopted to provide for the reclamation and utilization of useful mining by-products, we can expect the same hardships on the people and the manufacturing industries as obtained last winter.

M. S. Hachita.[1] In preparing anthracite, there are two kinds of waste produced: first, fine material, the largest pieces of which are no bigger than $\frac{3}{32}$ in., which is so fine that heretofore it has been considered unmarketable; second, rock refuse. The latter material has been picked out during the process of preparation. The production of culm at present is approximately 7½ per cent of the total output.

TONNAGE OF CULM AVAILABLE

The average culm production from the beginning of the industry to the present time (1820–1918) is about 15 per cent of the tonnage mined. According to the statistics, the anthracite mined and shipped from 1820 to January 1, 1918, amounts to 2,332,673,250 tons, so that the amount of culm produced during the same period is 349,901,000 tons. Out of this, about 50 per cent has been taken into the mines to support the roof and washed away, leaving 174,950,000 tons available above ground in the whole anthracite field.

The rock refuse, which consists of slate and bony coal, amounts to approximately 10 per cent of the output, or about 233,267,000

[1] Chemist, Lehigh Valley Coal Co., Wilkes-Barre, Pa.

tons. The slate which occurs in anthracite measures is entirely unlike that used in roofs, sidewalks, etc. On the other hand, it contains from 28 to 48 per cent of combustible material, while the bony material contains from 45 to 70 per cent of combustible. The rock banks, composed of slate and bone, contain at least 50 per cent of the heat in commercial anthracite. At the present, rock refuse is not utilized as fuel in the anthracite field.

The fine material which is locally known as culm, slush, or silt, contains 70 to 85 per cent of combustible material. It is therefore a good fuel, provided proper means of burning it can be used. During the last sixty years a large amount of experimenting has been done with a view of utilizing this material.

A thorough research relative to the utilization of anthracite culm was made by the Lehigh Valley Coal Co. in 1913, at the Spring Brook boiler plants, near Hazleton, Pa.

For this purpose there were arranged a battery of four cylindrical boilers 33 in. in diameter and 30 ft. long; one smoke stack 33 in. in diameter and 33 ft. high; a total grate area of 132 sq. ft., having air space of 19.8 sq. ft., or 15 per cent of the total area.

The fuel was burned under forced draft of ½ in. water gage. The mixture consisted of culm and bituminous coal. In the test the fuel was fired in alternate layers of bituminous coal and culm, also a thorough mixture of both fuels in various proportions. It was soon found that a thorough mixture of culm with bituminous coal was the better method and this method was therefore used throughout the tests.

MIXTURES OF SOFT COAL AND CULM

The first series of tests consisted of 30, 50, and 70 per cent of run-of-mine coking coal mixed with 70, 50 and 30 per cent of culm from the Hazleton Shaft Colliery of The Lehigh Valley Coal Co. The second set of tests consisted of a mixture containing pulverized bituminous coal. The biggest pieces of soft coal in the mixture were not larger than 2 in. in diameter. Both fuels were thoroughly mixed in the above proportions by the use of shovels, and fired. The result of these tests shows that, in every case, the pulverized bituminous coal produced the better results.

The non-coking bituminous coal was also tried but it did not produce the same results as those produced by the coking coal. The reason why the coking coal is better adapted to mix with the culm lies in the fact that the coking coal fuses at a comparatively

low temperature and the fusion takes up the particles of culm, forming a homogeneous mass of fuel which burns uniformly. The results of these tests show that a mixture consisting of 30 per cent of culm and 70 per cent of coking bituminous coal produced a water evaporation equal to that afforded by the straight bituminous coal. It was also noticed that the mixture was easier to burn than soft coal alone. This is due to the fact that when soft coal alone is burned, the fuel bed becomes a hard, coked mass requiring considerable poking to effect complete combustion, whereas in the case of the mixture, the coked fuel is more easily handled by the fireman. It was also noticed that the fuel produced little smoke.

In September, 1917, E. E. Loomis, president of the Lehigh Valley Railroad Co., was informed by F. M. Chase, vice-president and general manager of the same company, about the formula of the mixed fuel with the view of burning the mixture on stoker engines. It was then decided to try it on big freight locomotives running between Hazleton and Lehighton, a distance of 26 miles. In this test the fuel consisted of 30 per cent culm and 70 per cent of stoker coal or slack. The train was made up of 50 cars of coal hauled from Hazleton to Lehighton, and returned to Hazleton with 65 empty cars. There was no trouble experienced in the test and in later evaporation tests made on locomotives using the mixed fuel and straight bituminous coal.

MORE STEAM WITH MIXED FUELS

The results of these evaporation tests showed that the mixed fuel produced approximately 30 per cent more steam than straight bituminous coal although the calorific power of the latter was considerably greater than that of the mixed fuel. This is due to the fact that the complete combustion of the hydrocarbon is possible in the mixed fuel, whereas, in burning straight bituminous coal, the greater part of these valuable hydrocarbons is lost as smoke.

B. S. Murphy. Our plant was designed to use the small sizes of anthracite coals and under normal conditions we have no difficulty in doing so even with the No. 4 or dust. The increase in the impurities with a relative decrease in calorific value due to colliery methods such as mining, failure to wash in the larger sizes, such as No. 1, the large amount of shale and pebbles in the so-called river coals, dredged coals, etc., has placed a different aspect on the problem; but one that can be solved successfully for such plants as are now equipped or will procure the necessary equipment.

The coal used varies from straight No. 1 buckwheat to No. 3 and No. 4, the latter, or dust, using the recommended A.S.M.E. scale, being that passing through a $\frac{3}{32}$-in. opening. Our so-called No. 3 has from 45 to 60 per cent dust and the No. 4 over 60 per cent and up to 85 per cent through $\frac{3}{32}$-in. screen.

INFLUENCE OF SIZE OF COAL

It is most desirable from both an economic and operating standpoint to adhere to one size of coal for as long time periods as possible. It is impossible to maintain good economy when the run of coal for the boilers changes continually from the smaller to the larger size and back again, for an entirely different method of manipulation is necessary. On the other hand, if the fuel is a well-mixed one, say, one as follows: 15 per cent of No. 1, 20 per cent of No. 2, 40 per cent of No. 3 and 25 per cent of No. 4, and remains as such, it can be handled well and in fact is easier to handle than the No. 3 for poor firemen.

The reason for the mixture of bituminous coal with the anthracite is twofold: (*a*) to act as a binder and (*b*) to increase the calorific value. With the large size, No. 1 buckwheat, our practice is to add no soft coal. Here we find that the soft coal is a detriment, forms clinker with the impurities and makes the firing more difficult.

With the small sizes the primary function with the good coals — 11,500 B.t.u. to 12,000 B.t.u. — is to act as a binder to hold the fire on the grates, and with the poor coals to increase the calorific value as well.

The amount necessary to bind the fuel varies from 5 to 10 per cent, say 7.5 per cent as a mean; this again will depend, however, on the quantity of the No. 4 size. The smaller the coal particles the greater the amount of bituminous required, until with the straight No. 4, say 80 per cent, from 15 to 20 per cent should be used.

Another use for the bituminous coal is the "building of bottoms" in the fire and the repairing of holes. This is especially true with the untrained firemen, and our practice is to have a small bunker of bituminous on the fireroom level where the men can get a few scoopfuls from time to time for this purpose.

MIXING BITUMINOUS WITH SMALL ANTHRACITE SIZES

It is of the utmost importance to have the bituminous well mixed with the anthracite, for the better the mixture the less re-

quired and the better the economy. In small plants where the coal is brought to the fires in barrows it should be turned in on the floor similar to mixing concrete.

Our practice at the present is crude and consequently does not give the best results. The coal is delivered in hopper-bottom cars and a predetermined number of buckets of bituminous is added from a storage pile to the top of the car by means of a locomotive crane. The coal is then dumped on conveying belts delivering the mixture to a crusher and thence to the overhead bunkers. In the summer this method works fairly well, but in the winter, with the coal frozen, the soft coal may be delivered to the bunkers some 30 or 40 min. before the coal in the car is all unloaded, because the pockets thaw first and the soft coal goes through a long while before the ends of the car thaw enough to flow. This results in uneven distribution to the boilers, some chutes having far too much soft and others not enough. Here again the emergency bunkers on the fireroom level come into play.

An element that enters into hand firing of small anthracite sizes is the vast formation of soot or flue ashes. It is necessary to carry considerable draft and the result is that some of the combustion is similar to that of powdered fuel; it never reaches the grates after leaving the fireman's shovel, it either ignites and burns in the air or is brought over to the rear connections in the form of coke. The greater the rating, the larger the soot deposits due to the greater draft necessary; but even working the boilers at light loads, a very large amount is formed. Our boilers were designed with this in view and have a large space in back of the bridge wall to allow this soot to accumulate, and soot pipes extending down into the ash cellar to allow it to run directly into the ash cars; our economizers are also equipped with soot pipes for this purpose. With the No. 4 coal and insufficient soft coal in the mixture, we will build up soot four or five tubes high between cleanings of soot hoppers, or in six hours.

To give an idea of the magnitude of this, we have had months when the weight of the soot removed was 10 per cent of the weight of the coal fired; this is exceptional, and it should be from 6 to 7 per cent. It may be of interest to note that at times an analysis of the soot shows a slightly higher calorific value than the coal it was made from, due to the fact that the soot is principally coked coal without impurities. We have attempted to burn this but with no success. However, if a small briquetting plant with a cheap binder were available, it could be done successfully. The soot formed by

the stoker is naturally but a small percentage of that in the hand-fired boiler.

The gates are of the inclined dumping type, with an area of 190 sq. ft. per boiler of 900 hp. The air spaces are 20 per cent with one and 9 per cent with the other.

BEST THICKNESS OF FIRE

Our practice is to carry as thin a fire as possible without danger of blowing through and forming holes. The thickness of fire hinges on the formation of a good bottom after cleaning, say about 3 to 5 in. thick, and then building up as slowly as possible. We clean before the service hour and start cleaning again as soon as the peak is over, some two hours — if the fires will stand that long. The thickness of the fires at the time of cleaning is problematic, depending on the load carried and the coal; we have had them from 20 to 24 in. or even heavier, but 16 to 18 in. will be nearly an average.

The amount of draft available is of the utmost importance as it is impossible to use the small sizes without a high ashpit pressure. At our Terminal Building in New York we can carry the normal load, somewhat below boiler rating, with natural draft, but here, on account of the great height of the stack, about 320 ft. above the top of the grate, we have an unusual condition: when the boilers are brought to rating the natural draft has to be augmented by blowers. At the Jersey City Power Station we use from 2½ to 3 in. water gage between loads and from 4 to 7 in. during the peaks, depending upon load and condition of fire.

The rate of combustion varies with the load and coal. During our peak hours, with poor coal we burn from 40 to 60 lb. per sq. ft. of grate per hr., while for the whole 24 hr. the rate will be from 20 to 25 lb.

We have but one stoker installed at the present, a Coxe (chain grate), but we are now equipping all of our hand-fired boilers with this type of stoker.

HANDLING CULM FROZEN IN CARS

An important consideration in the use of culm for fuel is the thawing of coal during the winter months if the coal is delivered to the plant in cars. On account of its compactness the moisture freezes to a hardness equal to that of lean cinder concrete and a "bull-point" chisel is necessary to cut it. If a thawing house is not available, special provisions will have to be made. Our practice is to use from 8 to 12 thawing pipes per car — 1¼-in. extra heavy pipe

fitted with cap and tee at upper end, a drive point at the lower end and the lower portion of the pipe above the drive point perforated with a large number of small holes. The pipes are entered in the top of the pile in the car and after the thawing begins are driven down from time to time with a wooden maul. The pipes connected in series are fed with 140-lb. superheated steam. It requires from two to six hours for this and then the car is brought over the unloading hopper. The car hopper will be iced so badly that it also will have to be thawed, especially the operating mechanism. To do this we use portable nozzles made up of three 1-in. pipes clamped together with a common steam connection to a rubber steam hose, the outlets of the pipes being staggered to make an equilateral triangle and bent at right angles to the body of the pipe. This will thaw the car-door mechanism within a few minutes, so that the doors can then be opened. The worst frost will be found here on account of the drainage accumulation at the low parts, but about ten minutes with two nozzles will start the coal running in the worst car, opening a hole to the top of the car and allowing the coal thawed by the top pipes to run out. It must be borne in mind, however, that this will require a large amount of steam; we find this equivalent to 10 tons of coal per 24-hr. day for from 12 to 18 cars unloaded. It is also necessary to have quite a gang of men working in the car; we use from 4 to 8 to the car because considerable picking is necessary where the coal adheres to the metal sides of the car.

W. G. Diman. We have at the plant of the Amoskeag Manufacturing Company 185 Manning boilers, of which 169 are running today; all boilers are fitted with Jones underfeed stokers. About two years ago we began to get small quantities of anthracite screenings and refuse; the amount has been increasing until we are now burning hard coal of No. 2, No. 3 and bird's-eye sizes straight under 135 boilers, and hard coal mixed with a small percentage of soft coal under the other boilers.

When we began to receive the hard coal we experimented with various mixtures, but finally used the fuel straight on each to get comparisons of the various grades to assist us in buying. We found that with the regular installation of the Jones stoker the coal was pushed over on to the dead plates and lay idle there with no chance for air to mix and consume the coal. When the buckwheat was hot it acted like sand and the tuyere blocks on the side of the retorts had a tendency to blow the coal over to the side and pile it up. In

order to make an even fire and to get better distribution of air for burning, we put in pin-hole dead plates with about 270 ¼-in holes, or a total increased air area of about 14 sq. in. The plates were not faced off but were rough castings, which allowed considerably more air to get into the fire. I think still better results would be obtained if we cut off some of the air spaces in the tuyere blocks and added air space in the dead plates. This would reduce the open spaces in the bed caused by the tuyeres' blowing away the coal and produce a more even fire. Some of the coal drops into the pits, which have to be cleaned out to prevent their burning and forming explosive gases.

We carry a light fire, about 6 in. to 8 in. thick, which allows the air to get through. About 2 in. water pressure is carried at the tuyere blocks and no draft in the uptake. We burn about 600 lb. of coal per hour or about 26 lb. of coal per sq. ft. of grate. The larger the grate and the easier the fire is run, the better the results.

We have had to run on anthracite coal as high as 25 per cent in ash. When doing this we have considerable trouble with the fires and handling the ashes. We find that the more we handle the fires the greater the loss. We cannot get efficient results out of coal containing much more than 20 per cent ash and if we should get coal containing 40 per cent ash it would be useless to us. In view of the transportation problem and freight rates, the place to burn any coal having about 25 to 30 per cent ash is at the mines, where they can equip to burn the specific fuel which is produced.

RESULTS OF TESTS OF MIXTURES

The following notes show what results we obtained from our tests, all of which ran 12 hours. Each lot received is tested before and during shipment to see if its quality compares favorably with other coal of the same kind.

An average of 20 tests of straight soft coal of different qualities gave an efficiency of 76 per cent with an evaporation from and at 212 deg. per lb. of dry coal of 10.7 lb. The ash averaged 8 per cent. These tests were made without any perforations in the dead plates.

One test of a mixture made with two-thirds soft coal and one-third buckwheat gave an efficiency of 74.7 per cent with an evaporation of 9.93 lb. from and at 212 deg. per lb. of dry coal; and the ash averaged 11.4 per cent. This gave a good fire but, of course, required a little more work and attention from the firemen. The load could be easily carried under these conditions.

An average of two tests of a mixture made with one-half bank coal and one-half soft coal gave the following results: efficiency, 58.3 per cent; evaporation from and at 212 deg. per lb. of dry coal, 6.97 lb.; ash, 19.73 per cent. This coal was somewhat dirtier than the average and required considerable work from the firemen. We burned about 670 lb. of coal per hour and ran about 93 per cent of the boiler's rating. The results of all our tests with culm prove that it is much below buckwheat and smaller sizes in evaporation and the only way to get it on a basis with buckwheat is to increase the soft-coal percentage, which of course increases the mixture price. It would take three parts soft to two parts culm to equal two parts buckwheat and one soft.

An average of two tests made with a mixture of two-thirds buckwheat and one-third soft coal gave an efficiency of 66.2 per cent with an evaporation of 7.96 lb. of water from and at 212 deg. per lb. of dry coal; ash, 14.83 per cent. These two tests were made on a little better grade of bank coal. We burned 676 lb. of coal per hour, and obtained 95.1 per cent of the builder's rating. The boilers are of 150 hp. each. We used a draft in the tuyere blocks of 1.59 in. and 0.07 in. in the uptake. When burning this mixture the fire burns well but needs close attention. A light fire must be carried.

An average of eleven tests of anthracite refuse, which includes bank coal and culm (no soft coal used), gave the following results: efficiency 55.7 per cent; evaporation from and at 212 deg. per lb. of dry coal, 6.75 lb.; ash averaged 17.8 per cent. We consumed 628 lb. of coal per hour, obtained an average of 78.4 per cent of the builder's rating and used 1.86 in. of water pressure at the tuyeres. This was an experimental mixture made to see what it would do.

An average of seven tests with prepared anthracite screenings of No. 2 and No. 3 buckwheat and bird's-eye without any soft coal gave the following results: efficiency 59 per cent; evaporation from and at 212 deg. per lb. of dry coal, 7.47 lb.; ash averaged 14.5 per cent. We consumed 742 lb. of coal per hour, obtained 96.7 per cent of the builder's rating and used 1.73 in. of water pressure at the tuyere blocks.

We made one test using one-half culm and one-half buckwheat, which gave an efficiency of 53.2 per cent and obtained an evaporation of 6.13 lb. from and at 212 deg. per lb. of dry coal. The ash averaged 21½ per cent. We consumed 680 lb. of coal per hour and obtained 72 per cent of the builder's rating. To do this we used 1.87 in. draft at the tuyeres. The culm, of course, has a tendency to pull the buckwheat down.

In order to burn anthracite screenings and refuse successfully under our conditions, a Coxe stoker specially built for this grade of coal should be used, or a small amount of soft coal must be mixed in. This mixture must be maintained at all times and the better the mixture the better the results of combustion, for the successful burning depends entirely on the mixture.

Some of the buckwheat clinkers and some of it will break up into smaller pieces, mixing with the fire, which makes it hard to clean. The fire should not be disturbed any more than possible. It is not good judgment to use a slice bar more than is necessary. The fires should be kept medium and the hoe should at all times be able to touch the grate. When hot, this class of coal resembles sand and a hoe can easily move it when necessary and handle the dirt. The lighter the fire, the better are the results. Unless the firemen are watched they tend to carry heavy fires with more draft. With an 8-in. fire we can easily burn 1000 lb. of coal per hour using a 2-in. draft at the tuyeres. The coal should run as even in size as possible.

We can burn screenings successfully if we obtain 20 per cent soft coal. It is more economical to burn straight soft coal than screenings, unless the equipment is installed for the burning of this class of coal. Two years ago last April we ran on soft coal only. We burned that month 10,352 tons of coal as against 13,689 tons of practically hard coal (about 20 per cent of soft coal) this last April. Our steam load this year was 369,512 kw-hr. less for the month of April, or about 12 per cent of the total steam load.

If we take hard coal at $6.25 per ton and soft at $10 it would make the balance in favor of soft coal, provided the load was the same and we took into consideration the added cost for boiler-house labor and handling ashes.

We recently got a cargo of Dominion coal, which apparently is high in volatile. We burned this with buckwheat—a quarter of Dominion soft coal and the rest buckwheat—and we secured the best results that we have ever had. Dominion coal burned straight is poor coal because it clinkers badly, but it has a tendency to mix with anthracite, and the anthracite holds down the volatile elements.

William P. Frey. There is only one kind of anthracite waste and that is material containing 35 per cent or more of incombustible, be it chestnut coal or No. 4 buckwheat. Since the development of the process of cleaning No. 4 buckwheat (through ⅛-in. round mesh

[1] Fuel Engineer, The Lehigh Coal & Navigation Company, Lansford, Pa.

and over $\frac{1}{16}$-in. round mesh) and No. 5 buckwheat (through $\frac{1}{16}$-in. round mesh) these two products have gained a firm foothold and have come to stay.

No. 3 buckwheat and No. 4 buckwheat are two excellent stoker fuels if there is a proper stoker installation. No. 5 buckwheat is

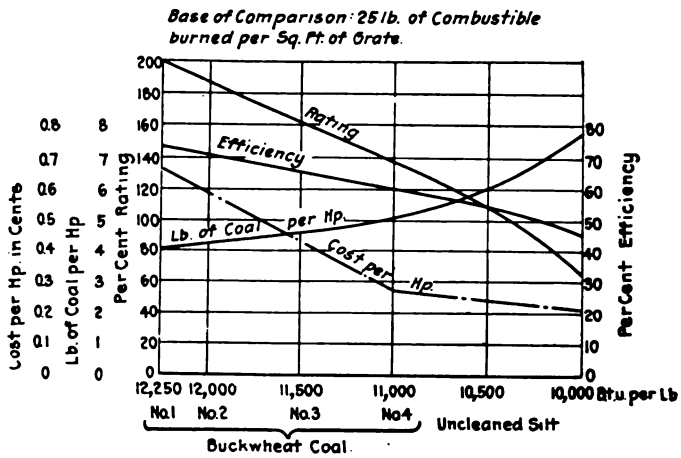

FIG. 8 PERFORMANCES TO BE EXPECTED WITH VARIOUS BUCKWHEAT GRADES

(Cost per Hp. and Lb. of Coal per Hp. in diagram are per hour.)

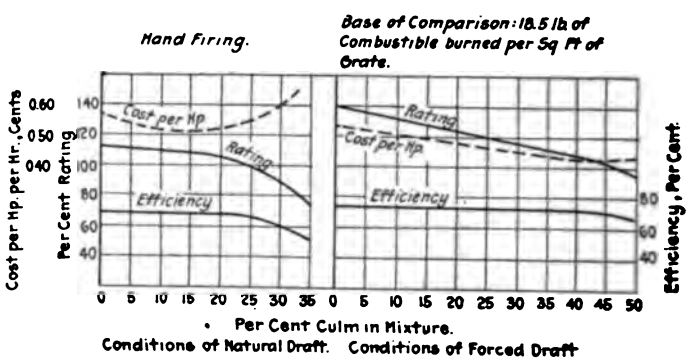

FIG. 9 PERFORMANCES WITH MIXTURES OF NO. 4 BUCKWHEAT AND SOFT COAL, HAND-FIRED

too light for stoker firing and should be briquetted or used for pulverized coal purposes. To the users of soft coal, hand- or stoker-fired furnaces, I cannot too strongly recommend mixing No. 3 buckwheat or No 4 buckwheat with their bituminous coal. The curves in Figs. 8 and 9 clearly indicate the possibilities of these mixtures for stoker practice although they pertain only to hand-firing practice. All prices

are based on the following scale per long ton, f.o.b. mines: Buckwheat No. 1, $4.10; No. 2, $3.30; No. 3, $2.15; No. 4, $1.25; No. 5, $1.00; uncleaned silt, $0.65; bituminous run of mine, $3.40 (per short ton).

FIRING OF ANTHRACITE BUCKWHEAT

Table 11 represents the attempt to tabulate in an easily understandable form the practical operating condition of industrial power plants with highly varying loads. As it was found that a rate of combustion of 25 lb. of dry coal per sq. ft. grate surface per hour was very economical for all sizes, this rate was adhered to as closely as possible by adjusting the speed of the grates and the air supply. As a rough guide for the boiler operatives the blowers have to be set to deliver 20 cu. ft. of air per maximum horsepower. The air control goes hand in hand with the CO_2 recorder readings that read 12 per cent on the average and the stack temperatures, which are to be kept below 500 deg. fahr. If the stack temperatures are high, the speed of the grate must be increased, the thickness of the coal fuel bed reduced, the air pressure under the grate lowered, but the rate of combustion maintained as constant as possible. It is very important to understand that the figures given in the column for grate travel in feet per hour are relative to 25 lb. of coal per sq. ft., which means that if the grate runs at 16.2 ft. in the case of No. 3 buckwheat, the bed must be carried 6 in. thick. If it is desired to carry only 4 in. the speed of the grate must be increased 6 : 4 = 1.5 times to keep the same rate of combustion. It has to be understood, too, that 25 lb. per sq. ft. per hour is by no means the highest possible rating. The maximum rating obtainable according to our experience is: No. 1 buckwheat, 40 lb; No. 2, 35 lb.; No. 3, 30 lb.; No. 4, 27 lb.; uncleaned silt and No. 5 buckwheat, 25 lb. or less. These figures apply to a Coxe stoker with 7 per cent air space in the grate.

Good practice will keep the air pressures in the tuyeres as near as possible to 1 in. at the stoker front, graduating down to 0.2 in. at the refuse end of the grate.

The operating equipment includes: automatic feedwater and damper regulators; recorders of steam flow, CO_2, feedwater temperature, steam pressure, and stack draft; draft gages and long-distance thermometers.

FIRING OF ANTHRACITE AND SOFT COAL MIXED

Buckwheats Nos. 3 and 4 are well adapted for mixing with soft coal if they are clean and the mixing is well done. These two con-

ditions are absolutely essential and cannot be emphasized enough. The method of firing need not be changed, although there should be a tendency to fire thin and to damp off. The green coal should be thrown on when the fire is white hot, after leveling, for instance, and then there will be a very pronounced coking effect that will bake the No. 4 buckwheat to a coarsely granulated fuel of about pea-coal size. The fire must be kept loose at all times and will stand very hard blowing. Almost any good grade of grate bar is suitable, up to about ¾-in. openings, provided enough kindling is left on the grate after cleaning to cover the grate. The most gratifying feature of the mixture burning is that it does away with all hard clinkers,

TABLE 11 OPERATING RESULTS OF ANTHRACITE BUCKWHEATS

750-Hp. Maxim Boiler — Coxe Traveling Grate. Average Steam Pressure, 125 Lb.

	No. 1 Buckwheat	No. 2 Buckwheat	No. 3 Buckwheat	No. 4 Buckwheat	Uncleaned Silt
Average hp. of test (24 hours)	1500	1395	1200	1010	495
Maximum hp. of test	1750	1600	1400	1100	650
Average per cent rating	200	186	160	134	66
B.t.u. per lb. of dry coal	12250	12000	11500	11000	10000
Combined efficiency of boiler, furnace and grate, per cent	74	70	65	61	45
Equivalent evaporation from and at 212 deg. per lb. of dry coal, lb	9.35	8.77	7.7	6.9	4.6
Dry coal consumed per hp. per hr., lb	3.69	3.93	4.48	5.00	7.5
Dry coal per sq. ft. grate surface per hr., lb	25	25	25	25	25
Boiler hp. per sq. ft. grate surface	6.8	6.36	5.5	4.9	3.3
Grate travel in ft. per hr	16.6	16.5	16.2	15.2	11.1
Cost per hp. per hour in cents[1]	0.67	0.58	0.43	0.27	0.21

[1] These figures correspond to prices at the mines and have to be adjusted to meet the various freight rates.

which is especially welcome in stoker practice, particularly in underfeed stokers.

The curves in Fig. 9 show the results obtained in burning soft coal mixed with No. 4 buckwheat in a hand-fired Newburgh fire-tube boiler. The rate of combustion (amount of coal to be shoveled) was kept constant. All coal was crushed to smaller than 1½-in. round mesh.

BRIQUETTING OF ANTHRACITE WASTE

Either No. 4 buckwheat, or No. 5 buckwheat, or the two mixed, or uncleaned silt, can be briquetted successfully. Anthracite bri-

quetting has passed the stage of experimentation. The binder material is available, and with the concurrence of all concerned not a pound of anthracite waste should go down the rivers again. That briquetting is a commercial success is proved by the fact that it raised the price of No. 5 buckwheat from 65 cents to $1, leaving still a small margin of profit, and by the ever-increasing output of our Lansford experimental plant, which shows the following tonnage figures:

Year	1915	1916	1917	1918 (to Apr. 30)
Tons	3,983	11,194	31,034	18,500

Conclusions: To the careful reader it will be evident from the preceding that it is not only desirable to burn cleaned No. 4 buckwheat, but it is at the same time most economical if ample grate capacity is provided; and there will go hand in hand with the preparation of No. 4 buckwheat, the washing and concentrating of No. 5 buckwheat, which can be briquetted or pulverized to a very valuable fuel, relieving some of the domestic sizes. But the results obtained show still more conclusively how important it is to use proper methods of firing and mixing, and the prime importance of keeping the market free from all fake products of unclean No. 4 or No. 5 buckwheat, uncleaned silt, or low-grade briquets.

G. H. Sharpe. The Derby Gas Co., Derby, Conn., endeavor to provide, during the season of open navigation on the Housatonic River, an ample reserve stock of bituminous coal to carry the electrical department through the winter and early spring. The demands during the past winter exceeded the estimate, owing to the emergency power supplied to Waterbury, Conn., and to tide over it was decided to accept an offer of about 11,000 tons of No. 2 and No. 3 buckwheat, on which deliveries started in the latter part of March. The 11,000 tons were purchased under three contracts, the average analysis of which is about as follows:

Ash, per cent	20.52
Moisture, per cent	8.20
B.t.u. as received	10,638
B.t.u. dry	11,587

An average of 7000 lb. of buckwheat is loaded from the storage pile into a truck, and the truck is then filled up with bituminous, giving about 55 per cent of buckwheat per load. This is dumped at the power station, passing through a crusher and conveyor, and into

the bunkers, resulting in a uniform mixture. From the overhead bunkers, the coal is delivered through a traveling weigh larry to multiple-retort underfeed stokers serving two 600-hp. Babcock and Wilcox boilers. The mixture is, as stated, about 55 per cent No. 2 and No. 3 buckwheat.

The fire carried is much thinner than with bituminous, and with a 2½- to 3-in. draft. The output of the boiler is reduced because of the lower heat value of the fuel.

The clinkers and ash are increased, resulting in a marked increase in cost of operation, as ashes are loaded by hand to trucks, pending completion of the new boiler room; but clinkers are more easily broken, so that less coke is lost in cleaning the dumping grate.

We are burning 2.20 to 2.21 lb. of coal per kw-hr. at the switchboard, with a maximum output of 6800 kw. and an average of between 5000 and 5500 kw., giving an overall plant efficiency of about 11.9 per cent.

The buckwheat costs $1 less than the bituminous, but the increased cost of ash disposal and lower heat value do not warrant additional purchases. The stokers handle the 55 per cent mixture readily, and I have no doubt that we could have made an equal showing, based on heat values, with 75 per cent or even 85 per cent of buckwheat.

R. Sanford Riley. We in the stoker business who are primarily interested in the burning of bituminous coal are frequently asked as to the amount of anthracite coal that may be mixed with bituminous. To answer this question intelligently we should know the characteristics of both the bituminous coal and of the anthracite coal that the questioner has in mind. The proportions mentioned by the previous speakers are very good; we find that up to 50 per cent of anthracite may be used.

Nearly all stoker manufacturers are advocating the necessity for large stokers. We think that the stoker is really the limiting factor. The maximum of stoker capacity should be put under the boiler. The reason for this is that the boiler investment cost per horsepower is very much greater than that of the stoker. I would like to emphasize that the mixture of anthracite and bituminous must be thorough; one cannot burn first a patch of anthracite and then a patch of bituminous.

P. B. Wesson. We have a small Manning boiler plant which we fire one-half anthracite and one-half bituminous; and we mix

the coal by taking the small industrial dump cars and filling them half full of anthracite, and then at the other end of the trestle filling them with bituminous. The cars are then dumped on the boiler-room floor.

A. G. CHRISTIE. Last winter we purchased a considerable quantity of anthracite "yard sweepings" from domestic coal dealers for use in Taylor stokers under Babcock and Wilcox boilers in our University plant. This coal contained 16 to 20 per cent ash and averaged about 11,000 B.t.u. In general these screenings came from coal mined before the shortage occurred. It could be burned with perfect satisfaction in the stokers even at overloads when mixed as high as three parts of anthracite to two parts of Somerset semi-bituminous coal.

Later several cars of washed culm were purchased with from 25 to 40 per cent ash running 10,000 to 7000 B.t.u. per lb. The ash had a low fusing point and formed immense hard clinkers in the furnace when mixed and burned with semi-bituminous coal. It could only be burned with an equal portion of the Somerset coal when the demand for steam was small. In the furnace the fuel had a dull appearance and the finer particles tended to blow over on to the dump plates. It cascaded badly on dumping and during the removal of clinker. On the whole we found the culm an uneconomical investment, although the yard sweepings proved economical when purchased at a reasonable price.

CARL SMERLING. Anthracite wastes such as culm and smaller sizes of buckwheat can be successfully consumed and burned, using a mixture of one-third anthracite and two-thirds bituminous coal, providing the bituminous is of a good coking quality and the fire can be carried 16 to 20 in. deep with natural draft of 0.7 in. at the stack breeching, and maintain a rating of from 125 to 150 per cent. Under these conditions the stoker can be operated the same as when burning the straight bituminous coal fire. It is absolutely necessary to have sufficient bituminous coal to raise the temperature of the fire high enough to get all the value out of the anthracite coal.

5 *What Instruments Are Useful and Desirable in the Boiler Room as Aids in Saving Coal?*

E. G. BAILEY. The answer to this question is: Meters that will actually *assist* the fireman to carry the load required of his boilers and at the same time obtain the maximum efficiency. The old idea

of having meters and recorders to "show him up" if he did not do his work well, when he usually did not know how to do it better, is wrong.

The word "meter" is used here in its broad sense to include all instruments, pressure gages, thermometers, etc., down to coal scales and wheelbarrows when they are used to obtain results and knowledge of the operating and efficiency conditions.

CONTROLLABLE LOSSES IN BOILER OPERATION

In selecting meters, the principal object is to obtain knowledge of the boiler capacity and efficiency and also the individual losses, especially those which are controllable. To accurately know the losses is of much more importance than to merely know the efficiency, for efficiency can only be increased by reducing losses, and if one knows that the losses have been reduced, he is positive that the efficiency has been increased. The principal controllable losses in boiler operation are: (1) combustible in ashes and refuse, (2) excess air, (3) unburned gas, and (4) high temperature of flue gases. There are also other factors from an operating standpoint that are of importance, such as the steam pressure, superheat, rate of steam output from each boiler, evaporation per pound of coal, etc.

RESULTS SHOULD BE KNOWN PROMPTLY

The really valuable results from complete boiler tests, such as those made by Dr. D. S. Jacobus at Detroit some years ago, are not obtained until the many calculations involving averages and totals are made and the relations between the various factors are determined. In other words, the total evaporation or even the rate of evaporation gives no information whatever as to efficiency until we know how many B.t.u. were expended in producing this steam, or at least know how many B.t.u. were lost in making it. Time is an important factor in boiler operation and the fireman should know final results promptly and continuously. It is therefore desirable to have meters of the fourth type, which indicate and record the relation between certain important factors as well as the condition, total and rate.

One of the important relations desired is that between rate of steam generation and rate at which fuel is burned. With liquid or gas fuels of uniform quality this is possible; but with coal, about the closest approach is the relation between a steam-flow meter and tachometer on the stoker drive. The latter, however, is a crude

means of determining the rate at which the B.t.u. are supplied to the furnace, and this is the real factor desired. It is doubtful if this will be satisfactorily attained, in the near future at least, due to the varying amount of coal fed per revolution of the stoker shaft and the varying quality of the coal, as well as variations in the amount of coal on the grate.

RELATION OF STEAM FLOW AND AIR FLOW

There is another relation, however, that is analogous to the steam-fuel ratio that is readily obtained and of even greater value. It is the relation between the rate of steam flow from the boiler and the rate of air flow which supports combustion for the generation of this steam. Air is a fuel just as much as carbon or hydrogen, and the amount of air required to develop a given number of B.t.u. is practically independent of the character or quality of coal being used. In fact, there is only 6 per cent difference between the B.t.u. developed per pound of air used to burn carbon and natural gas. This is much closer than most people are able to maintain the excess air in coal-fired furnaces. Natural gas is mentioned in this comparison because it contains a higher percentage of available hydrogen than any other commercial fuel.

There is ample evidence available to show that the relation between the steam flow and air flow is of value in assisting the fireman to maintain the most economical fuel bed and prevent undue losses in either excess air or unburned gases. This relation is also of great assistance to the fireman in obtaining maximum capacity from his boilers, for he quickly learns that it is impossible to make steam without the proper supply of air and if the maximum air supply is equivalent to only 200 per cent boiler rating, then 200 per cent boiler rating is all he can get, unless he is willing to sacrifice efficiency and produce high percentages of unburned gases. Such a loss is plainly shown by this relation as a deficiency of air.

Another important relation in boiler operation is that existing between flue-gas temperature and rate of steam output. We have only to refer to data plotted by Mr. Azbe [1] to see that there is a wide difference between results obtained from various boilers in different plants. While this relation depends upon the position of baffling and other features of design, it is perfectly definite for any one design, and a certain flue-gas temperature should exist for each

[1] Power Plant Efficiency, Victor J. Azbe, Trans. A.S.M.E., vol. 38, 1916 p. 722.

rate of steam output. Any deviation from this indicates dirty heating surface or leaky baffles, providing the proper relation exists between the rate of steam flow and air flow. Either a decrease or increase in excess air from the most economical amount will result in an increase in flue-gas temperature, except that a large percentage of excess air will reduce the temperature.

In boiler-plant operation there are several other factors which should be combined to show continuously the relations existing between them for the benefit of the fireman or operating engineer, whereby they can get at the true conditions and their causes with little mental effort and delay. A meter which shows a relation is in reality an automatic calculating machine which takes two or more factors and produces a tangible result which would otherwise require the reading of two or more instruments and reference to charts or tables.

The question often arises in selecting meters as to whether they should be indicating or recording. Some of the best power-plant engineers were strongly in favor of indicating meters for boiler-plant work a few years ago, but have now changed to be the strongest advocates for recorders. Practically the only argument that can be advanced in favor of indicating meters is lower initial cost and the lower cost of operation by elimination of charts.

ADVANTAGES OF RECORDING METERS

Some of the many advantages of recording meters are: Permanent records to show conditions existing throughout the twenty-four hours; averages, totals and operating characteristics may be checked at any subsequent time; and of even more importance is the fact that it helps the fireman to see, not only the conditions at that instant, but also what the conditions have been immediately previous, and thereby ascertain whether they are changing, and if so, in which direction. This alone is of sufficient value to warrant the use of recording meters in practically every instance, providing they are located in the position where the man in charge of operation can readily see the chart record in detail. A water tender will do much better work when he has a recording feedwater meter within sight than if the recorder were located in the engine room.

The firemen and operating men must have meters which serve as eyes whereby they can see through steam pipes and brick walls, so to speak, and actually know what is taking place. The meters that will give them true pictures in the most realistic and concrete form are the most useful in saving coal.

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Fig. 12

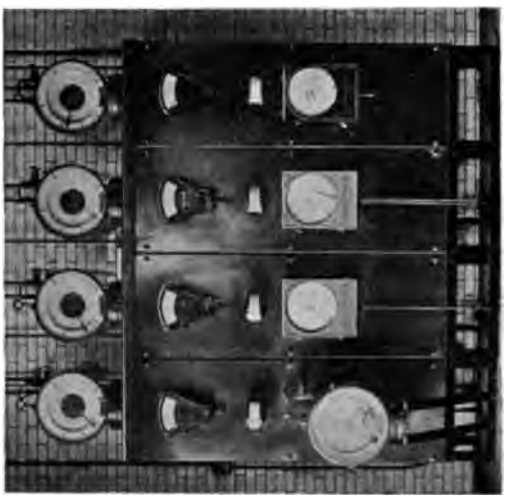


Fig. 11

Fig. 10

Figs. 10, 11 and 12 Boiler- and Combustion-Control Instrument Boards

c Afford an opportunity to use one instrument for diverse units

d Eliminate unnecessary fatigue of observing scattered instruments

e Assure ease and simplicity for testing.

These requirements are combined in the type of instrument board devised by the author, representative examples of installations being shown in Figs. 10 to 12.

The complete cost of these installations, including labor and material, averaged $2000, and the returns secured on this investment are usually equal to or better than told in the following report from a plant using from 150 to 250 tons of coal per week:

". . . It is evident that in the four months preceding the installation of the boiler control board, the savings on fuel, due to various steps taken, averaged $435 per month, while in the four months following the installation of the instruments the savings computed on the same basis averaged $1145. In other words, the increased savings, due solely to the *intelligent use* of instruments on the boiler-control board, was $710 per month, or $8620 on the annual basis, which means that the expenditure of $2080.46 for instruments of the said board is an investment which, in our case, yields over 400 per cent return."

The fallacy of economizing on instrument equipment or ignorant attempts to select "the most important" ones has only one rival in absurdity — the tendency to install instruments without giving the employees the opportunity to use them to advantage. Obviously, the operating men have no time, no facilities for research work, and little inducement to carry out investigations, standardize methods and set tasks. It should be the duty of the management to give them the necessary training and to assume responsibility for results.

A. R. Dodge. Pressure gages and water-gage glasses are absolutely necessary to the operation of steam boilers. Next in importance is a steam-flow meter for the purpose of showing the amount of steam being delivered by each individual boiler.

Steam-flow meters in service have shown that in nearly every case a battery of boilers as a whole may be generating the required amount of steam, but the several boilers making up the battery fall far short of assuming equal subdivisions of the total.

Steam-flow meters installed on each boiler show at once a boiler

which is "loafing," or one being forced too hard, conditions which cannot readily be detected in any other way. With this knowledge the necessary changes can be made in drafts, fires, etc., to equalize the steam output of the boilers. With the outputs equalized the danger of priming and burning out tubes and brickwork, due to excessive overload, is minimized.

Results obtained in many plants prove conclusively that the flow meters are a great aid to the firemen themselves in showing the results of their work. As soon as they learn that the flow meters show them the effect of changing the draft, fires, rate of feeding water, etc., they will be found using them as a working guide.

Holes and dead spots develop in fires, reducing the efficiency of combustion by allowing an excess of air. Should this occur, the steam output instantly drops, and with a flow meter installed on each boiler the fireman is warned that something is wrong.

Flow meters have been the means of indicating many other conditions which seriously affect the economy, such as leaky settings admitting quantities of air, burned-out baffles permitting a short-circuit of the gases, incorrect adjustment of feedwater regulators, or poor hand regulation, etc.

The use of draft gages, CO_2 recorders and a thermometer to show the superheat of the steam, in conjunction with a flow meter, enables the power-plant operator to keep a complete check on the performance of the boilers and furnaces, and to quickly eliminate faulty conditions as they occur and thereby to keep up the efficiency of the plant.

E. A. Uehling. The continuous CO_2 record shows up the process of combustion for every minute of the day. The indicator at or near the boiler front keeps the fireman continuously informed of what he is doing. It shows him in a few minutes the effect of any change in the rate of fuel and air supply that may be necessary to keep the steam pressure level.

WHAT THE CO_2 SHOWS

In hand-fired boilers the continuous record not only shows whether the proper per cent of CO_2 has been maintained, but also how often the fire was replenished, how long the fire doors were kept open, when the fires were cleaned, how long it took to clean them, and the improvement in the fire resulting from it. With an occasional check analysis by an Orsat the continuous CO_2 record becomes an unchallengeable exposition of combustion efficiency.

Combustion efficiency is the foundation of boiler efficiency, but it does not necessarily follow that maximum combustion efficiency will always result in maximum boiler efficiency. There is another factor of nearly, if not quite equal importance, viz., absorption efficiency. Absorption efficiency depends, first, on combustion efficiency; second, on the relation of heating surface to the rate of combustion; third, the routing of the gases through the boiler; fourth, the cleanliness of the heating surface inside and out, and fifth, air infiltration. The CO_2 meter should, therefore, be supplemented by at least two other instruments, viz., the pyrometer and the boiler draft gage, preferably the draft analyzer, which shows both the furnace draft (resistance through the fire) and the boiler draft (resistance through the boiler). The pyrometer does not by itself give reliable information, but if its readings are coördinated with those of the CO_2 meter and the boiler draft gage, a complete and reliable control over absorption efficiency is had. The boiler draft gage gives immediate notice of broken-down baffling, and in combination with the per cent of CO_2 its readings furnish an approximate index to the rate of combustion.

It would be useful to have, in addition to the foregoing, a steam-flow meter on each boiler, since they would furnish a quantitative check on every boiler and fireman in addition to the chemical and physical qualitative control which I have mentioned as necessary and adequate to attain and maintain maximum boiler efficiency dependent only on plant, fuel and operating conditions. The installation of a steam-flow meter is therefore to be highly recommended.

Wholesale control by means of water meter and coal weigher is most valuable to the manager in many ways in addition to those already mentioned, and any plant the size of which warrants the expense should install them.

R. P. Brown. The temperature in the furnace and the distribution of this heat throughout the boiler must be learned and studied carefully. The temperatures in the firebox are approximately 2500 or 2750 deg. fahr., which is too high for a permanent installation of a pyrometer. In the last pass the temperatures average about 1000 deg. fahr. and in the uptake about 400 or 600 deg. fahr. At these lower temperatures base-metal couples may be installed without danger of rapid deterioration. The temperatures in the last pass and uptake have been found to be comparative to those in the firebox; so that a working temperature is secured to which the fireman can conform.

If actual practice shows that 500 deg. in the uptake or a corresponding temperature of 1000 deg. in the last pass of a boiler results in securing the maximum efficiency, then the fireman should use this temperature as a guide. The slightest irregularity in firing or change in furnace conditions are readily noted before the corresponding change in pressure may occur. If the flues are dirty and sooty the heat cannot be absorbed and instead pass up the stack, and a correspondingly high stack temperature is secured. If the baffle walls become cracked or broken down the heat will not circulate properly, and again high stack temperatures.

In addition to the usefulness of temperature- and pressure-recording instruments, there has recently been evidenced an increased interest in electric tachometers for registering the speed of the shafts on automatic stokers. The rate of firing naturally bears a close relationship to the amount of coal used. A small generator is attached to the end of the stoker shaft by means of gear or sprocket and chain drive. It is so geared that about 15 to 25 volts are generated at a speed of approximately 1000 r.p.m. of the generator. This current produced by the generator is conducted to the instrument by means of wiring. As this can readily be strung for long distances, the instruments may be located wherever most desirable.

C. W. Hubbard.[1] The evaporation figure might strictly be classed as a "half truth." When this figure has been arrived at, without supplementary data, one man's guess is as good as another's as to whether the results obtained are all they should be.

The most useful instruments in the boiler room are draft gages, an Orsat apparatus, a CO_2 recorder, and recording thermometers for the feedwater line and the flue-gas temperatures. In addition to this, systematic tests of coal and ashpit refuse are necessary, for it is obviously unfair to expect the plant to operate at a given standard when it may be, and probably is, the case, under present conditions, that the fireman is being furnished with greatly inferior coal.

It has been a common experience of the writer to be able by thus studying the preventable losses in the plant, to make a saving of from 10 to 20 per cent within a period of a month, and when I say 10 to 20 per cent I do not mean a "paper" saving but I mean actual tons of coal wheeled into the boiler room.

R. H. Kuss. The question requires two sets of answers, because for the fuel engineer the entire range of instrument equipment may

[1] Fuel Engineering Co., New York City.

be made useful, whereas for the operating engineer of the usual grade a very limited number of instruments are of any special service.

Instruments an engineer can use to advantage are those which he can understand; those that prove useful are such as require little attention to keep operating and which reveal maladjustment by simple test. The most useful and simplest instrument for the boiler room is a draft gage, preferably of the differential type. A draft gage or draft-gage system, if continuously used, will show to the careful observer —

a Developments of leaks, uncleanliness, baffle failures, etc.

b Poor fuel-bed construction.

Less difficult to interpret but much less useful than draft gages are thermometers or pyrometers. The difficulties in using pyrometers are those only of placing the bulbs or couples in the proper places so that the indication may be a true one of the condition investigated.

Gas-analysis instruments, while highly necessary for more refined investigations, are so seldom used by operators of plants of the middle or smaller size that as a general proposition it is useless to place them in the operating engineer's hands. The writer strongly endorses the use of coal-weighing and water-measuring systems.

The great difficulty with the subject is that, however useful the instrument may be, the supervising or engineering forces of boiler plants neglect to employ them to an extent their value justifies. The conclusion is inevitable that they should be few in number but of the recording type rather than indicating alone. The reason is that a record affords the opportunity of not only checking up the operating performance while going on, but gives the managerial forces the opportunity of checking up the operating engineering forces.

Walter E. Bryan. When a number of boilers are connected to the same stack, it is particularly advisable to have each boiler equipped with a draft gage so that the gas passages can be regulated in the individual boilers with the result that more work will not be required of some boilers than others. Steam-flow meters are also advisable in stations where turbines are used and the flow is not pulsating. Readings of stack temperatures, CO_2, etc., should be taken at intervals, the latter with a view to calling attention to leaks in settings, etc. A recording CO_2 instrument arranged with connections to the various boilers is a valuable adjunct to the fireman.

B. J. DENMAN. I believe the most useful instrument in the boiler room to be the one which indicates the percentage of CO_2 in the flue gas. In larger stations, with boilers of 1000 hp. or more, an automatic CO_2 recorder is justified. In smaller units, each boiler should be equipped with a gas collector and the Orsat apparatus, to determine the percentage of CO_2. Samples should be analyzed at least once during each watch. We regard the steam-flow meter as essential and as important an instrument as an ammeter or a wattmeter on a generator, and even more important from an efficiency standpoint. It is important that efficiencies of all the boilers be known over a wide range of loads and that they be operated at the most efficient point. It is not of much value to determine the efficiency curve unless its indications are followed, and this can only be done by the use of a steam-flow meter. These will show not only the number of boilers to have in service, but the division of the load between the units. With the underfeed type of stoker, we believe it is necessary to have instruments indicating the draft over the fire and at the damper, as with this type of stoker practically balanced draft can be carried, and this is the furnace condition which is most conducive to economy, through a reduction in the infiltration of air. Flue-gas-temperature recorders are desirable, but not essential, as the release temperature will take care of itself, if the boilers are kept clean and operated at the most efficient point, except for short periods during the peak.

A. G. CHRISTIE. Our University plant contains Babcock and Wilcox boilers and Taylor stokers with steam-pressure regulation on the blast and a balanced-draft system on the flue-gas damper. We have found that the instruments which receive the attention of our firemen and enable them to obtain the best results are draft gages on the blast and over the fire, a pyrometer in the breeching and a CO_2 recorder. The latter takes much skilled attention but produces results. We have been experimenting with a new blast regulator which promises to give better results than the usual type. Steam meters combined with coal-weighing devices are most desirable additions to the plant. Then records of coal and water consumed can be posted daily for the information of the fireroom shifts.

C. E. VAN BERGEN. We regard the draft gage as necessary on every boiler. It is not possible for a fireman to know what amount of air is passing through or over his fires by simply looking at them. A steam-flow meter is valuable in showing the output of each boiler

and all plants, except small ones, should have a continuous record of CO_2.

It is our belief that any plant expending $5000 or more per year for fuel cannot afford to be without those instruments. The draft gage has shown us that we formerly did not have proper adjustment of stack damper and ashpit doors. The steam-flow meter has given us valuable information on our monthly and yearly output and the flue-gas analyzer shows us the result of careless firing.

6 *What Is Essential to the Economical Operation of Hand-Fired Boiler Furnaces When Using Soft Coal?*

HENRY KREISINGER. The right proportion of the air supply to the weight of the coal burned is the most essential requirement in the economical operation of hand-fired boiler furnaces. The removal of ash from the furnace is done with the object of keeping unobstructed the supply of air through the fire. The fireman shakes the grate or cleans his fires because the ash and clinker restrict the supply of air through the fuel bed.

In the boiler furnace about 14 lb. of air are necessary to burn 1 lb. of the average soft coal. This air must be introduced into the furnace in such a way that it is brought in direct contact with the coal and the gases rising from the fuel bed.

The Bureau of Mines has shown that in the hand-fired furnace, if the fuel bed is level and 5 to 6 in. thick, only about 7 lb. of air can be supplied through the fuel bed to each pound of coal burned. If an attempt is made to force more air through the fuel bed, only the rate of combustion or gasification is increased, and the ratio of the air to the coal burned or gasified remains constant.

The gases rising from the fuel bed contain a large amount of combustible, about 8 to 10 per cent of CO_2 and practically no free oxygen. To burn this combustible an additional 7 lb. of air must be supplied over the fuel bed, and should be supplied in a large number of small streams and as close to the fuel bed as possible, in order that it may be mixed readily with the combustible. This air is introduced through the dampers in the firing doors, through the cracks around the firing door, along the side walls and the bridge wall, in some cases through special openings in the bridge wall, and very commonly through holes in the fuel bed.

DIFFICULTY OF MAINTAINING PROPER AIR SUPPLY

In hand-fired furnaces it is difficult to maintain the 14-to-1 proportion of air supplied to coal burned, because usually the air is

supplied continuously and at a uniform rate, whereas the coal is charged intermittently at intervals of 2 to 20 min. duration. The ash is also removed intermittently at intervals of 3 to 24 hours, depending on its quantity and character. It is this intermittent feeding of coal that makes the proper proportioning of air to coal difficult. From the fireman's standpoint, soft coal consists mainly of two kinds of combustible, namely, volatile matter and fixed carbon. The volatile matter is that part of the coal which is driven off as gases and tars when the coal is heated, whether air is supplied to burn them or not. The fixed carbon is that part which stays on the grate after the volatile matter has been driven off and until burned or gasified by the air flowing through the fuel bed. When the fuel is 5 to 6 in. thick the fixed carbon is not completely burned, but a considerable portion of it leaves the bed in the form of CO. In the first 3 or 4 in. above the grate the carbon burns to CO_2, of which a large part is reduced to CO in the upper layer of the fuel bed.

Thus, immediately after firing while the distillation is taking place, the fuel bed acts both as a gas retort and a gas producer; after the volatile matter has been driven off the fuel bed acts only as a gas producer. Therefore, immediately after firing sufficient air is needed over the fuel bed to burn the gas from the gas retort and also from the gas producer. After the distillation has been completed only enough air is needed to burn the producer gas. With a constant air supply over the fuel bed it is impossible to have sufficient air to burn the gases completely while the process of distillation is going on without having too much air after the distillation has been completed.

ADJUSTMENT OF AIR SUPPLIED TO QUANTITY NEEDED

In order to have the right amount of air in the furnace at all times, two methods may be used: (*a*) The air supply over the fuel bed may be varied during each firing cycle; or (*b*) the distillation or the gas-retort process may be extended over the entire firing cycle.

There are devices to vary the air supply over the fuel bed automatically which, with proper attention, give good results. However, with the ordinary hand-fired furnace the fireman can approximate their action by cracking the firing door for a short period after firing.

The method under (*b*) is probably more practicable. Each new charge of coal can be heated slowly so that the distillation extends over the entire firing cycle.

With the coking method of firing the coal is placed in large charges on the front part of the grate, where it is heated slowly. When the distillation is nearly completed, the coal is spread over the grate and a new charge placed near the firing door. This method is feasible for heating boilers, but is objectionable for power-plant boilers.

For power-plant boilers the most practical and economical method is to shorten the period of firing so that distillation extends nearly from one firing to another. In order to eliminate the danger of piling the fresh coal on top of coal from which the volatile matter has not been completely distilled, half of the grate area should be covered at a time — the alternate method of firing — and the firing be so timed that half of the grate area is distilling volatile matter all the time. This may require that the firing be done at about 2-min. intervals, or even more frequently. The charges, of course, should be small so that there will be no tendency of the coal to form heaps; they should be spread over the thin spots of the fuel bed, avoiding the thick spots.

Frequent firing reduces the chance of the fuel bed's burning out large holes, which would let into the furnace too large an excess of air. With the caking or coking coals the holes in the fuel bed may not always be due to coal burning out faster in the thin spots, but to shrinkage of the fuel bed, which causes cracks to form. Once a crack is formed, the air rushes through and burns the coal on each side of the crack, rapidly making it larger. This explains why with eastern coking coals it is much more difficult to keep the fuel bed free from holes than with the free-burning coals such as come from the Illinois coal field. Frequent firing and the alternate method, to some extent, reduce the harm that may come from holes in the fuel bed.

EFFECT OF FREQUENT FIRINGS

Fig. 13 shows the effect of frequent firings of Illinois soft coal on the air supply and the composition of the furnace gases. The points connected with the solid, heavy line are the readings of CO_2 taken with an interferometer, and those with the dotted line the indications of CO_2, shown at the same time by a Uehling CO_2 recorder. The interferometer gives the CO_2 contents in the gases at the instant when the observation is taken, but the Uehling recorder has a lag of about 7 min. and a tendency to average the CO_2 readings over the entire firing cycle. The time of firing is shown by the black rectangles at the bottom of the chart. The inter-

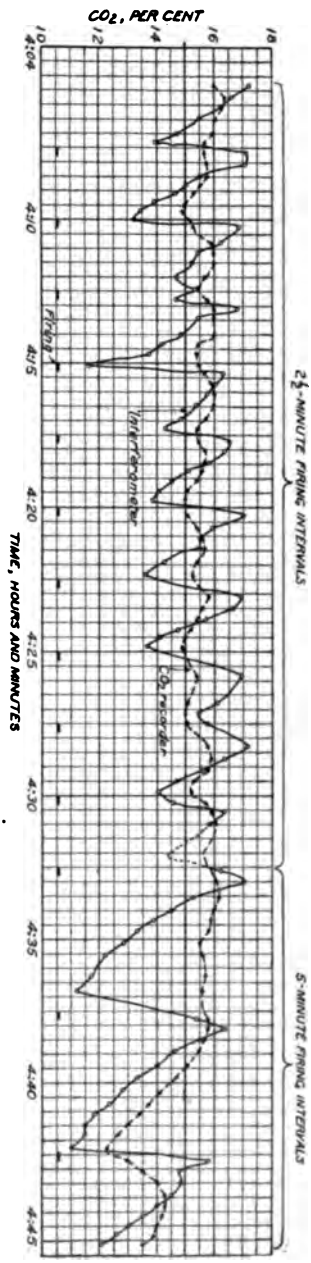


FIG. 13 CHART SHOWING EFFECT OF FREQUENT FIRINGS ON AIR SUPPLY AND COMPOSITION OF FURNACE GASES

ferometer shows plainly very high CO_2 immediately after each firing, followed by a rapid drop. This variation in CO_2 indicates very little or no excess of air after firing and considerable excess immediately before firing. The drop in CO_2 is much more pronounced with the 5-min. firing periods than with the 2½-min. periods, indicating that in the latter case the air supply is kept more nearly proportional to the weight of coal burned.

One half of the air supply was introduced through the grate and the other half over the fuel bed through fourteen 1⅛-in. nozzles. Both air supplies were measured. The nozzles were placed in the side walls and injected the air in horizontal streams close to the surface of the fuel bed. The grate area was 30 sq. ft. and the rate of firing was 22 lb. of coal per sq. ft. of grate per hour.

FIRING METHODS GIVING GOOD RESULTS

Good results can be obtained with a fuel bed about 5 to 6 in. thick. Heavy fuel beds offer high resistance to flow of air, making it necessary to carry high draft in the furnace and setting. High draft increases air leakage into the boiler setting and causes losses from the large excess of air. Furthermore, thick fuel beds cause excessive clinkering and the high losses connected with the frequent cleaning of fires. Higher rates of combustion can be obtained with thin fires than with thick ones.

The draft damper should be so adjusted that the air supply through the fuel bed is always just sufficient to burn the coal at the same rate it is fired. The accumulation of ash and clinker on the grate will gradually increase the resistance through the fire, and the draft should be accordingly increased. Sudden large changes in the damper should be avoided.

Fires should be thoroughly cleaned at regular intervals and at times when the load on the boiler is reduced, such as the noon periods. The side cleaning method by which one side of the grate is cleaned at a time is recommended. After cleaning, the fire should be built up gradually. A day's shift should start with a clean fire. Perhaps nowhere is a good start of such great advantage as in running a furnace.

INDICATING INSTRUMENTS OF PRIME IMPORTANCE

E. E. HUNTER.[1] One of the prime essentials to economical operation of hand-fired boiler furnaces when using soft coal is to have

[1] Chief Engineer, Oklahoma Gas & Electric Co., Oklahoma City, Okla.

boilers and furnaces equipped with the necessary instruments as guides or indicators, of which a reliable CO_2 machine and draft gages are the most important.

The method of firing to be used depends largely upon the quality of coal and upon the nature of the load to be carried. For a steady load a slow-burning coal which cokes nicely may be used to advantage, because there will be no sudden demands for steam and a thick fire can be carried, which should not be disturbed except when absolutely necessary.

On the other hand, with an erratic, unsteady load a quick, flashy coal high in volatile matter will no doubt give satisfaction, and the fuel bed in this case should not be very thick and should be fired lightly and often according to the steam demand.

The alternate method of firing is recommended by some, but I believe the best one is to fire every door, with the fire doors kept open the minimum length of time. The firemen should be given long and careful instruction in the manipulation of the dampers, guided by the draft gages, and should regulate their draft according to the demand for steam.

Fires should be cleaned at a time when there is the least demand for steam, and as quickly and thoroughly as possible.

Perhaps the best and most generally used method is where the live coals and coke are pushed or thrown to one side of the furnace, leaving the refuse, which is raked out. The clean grates are then covered with clean fire from the other side of the furnace, which is then similarly cleaned.

I believe that more fuel is wasted by operating with leaky boiler settings than in any other way. All boiler settings, therefore, should be kept up to the highest possible degree of tightness. This can be done by stopping up all of the larger cracks with some good filler and then applying a generous coat of a first-class plastic cement, which will effectually seal all small cracks and pores in the brick. The settings should be gone over at regular intervals by a competent man and repairs made where needed.

The most important thing, however, in the economical operation of hand-fired boiler furnaces, whether using soft coal or some other fuel, is to have a well-trained, efficient corps of men who are heartily in accord with their chief and his policies. This is extremely difficult to bring about, but it can be accomplished by systematic hard work, sprinkled with a little diplomacy. The governing head or superintendent, first of all, should be master of him-

self. This will command the respect and loyalty of those under his direct control. He should study human nature, for this will enable him to select the class of men who will stand by him. He, in turn, should stand by them, take an interest in their affairs, outside of business, and give ear and patience to any condition arising wherein their interests are involved.

GEORGE H. DIMAN. This is a subject in which I have been very much interested for over fifty years, but I have been discouraged many times by the indifference shown by the managers and owners of power plants. I know of no department in any manufacturing concern where there is as much waste as in the boiler rooms of our manufacturing concerns in New England.

FIRING METHODS THAT HAVE PROVED SUCCESSFUL

First, I should have the grates not over 7 ft. in length — 6½ ft. would be better — as it is impossible, if the grates are longer than this, to keep the back end of the fire covered. I should set the boilers no less than 4 ft. above the grates — 5 ft. would be better. This insures a good combustion chamber. It will be noticed that the boiler makers use practically the same size of ashpit door with a 250-hp. boiler that they do with a 600-hp. boiler. This gives a great supply of air near the doors, but none in the middle of the grates. I should dispense with the ashpit doors, cutting away the boiler front the full width of the grates. This gives an even distribution of air underneath the grates.

I should start with the fire 14 in. thick and try to keep it the same thickness through the day's run. I find time firing the best, and in our mills in Lawrence we adopted the system of firing every ten minutes, putting on the number of shovelfuls required to keep the fire the same thickness and maintain the power. I find that from 5 to 6 shovelfuls of coal is plenty. It takes about four to five minutes for a man to coal one side of two boilers and level the other side. This gives him five minutes to rest. I would recommend the boilers to be run about 50 per cent above rating. This would insure a very hot fire. Firing one side at a time prevents smoke. We have 44 boilers at our Wood Mills. They fire one-half of these boilers at a time — that is, one side, and level the other side of the same boilers. When they have finished, the men on the opposite side start and do the same. Every man has a chair to sit in, and in a 10-hour run the men are on their feet about half of the time.

I would use a good shaking grate, which keeps the fire free from

ashes, and would avoid slicing as much as possible, as this makes clinkers.

The dampers should be set so that all of the boilers will have the same draft. If the steam damper is used, I would have this adjusted so that it cannot close tight. When the damper closes tight, the furnace commences to make gas (CO), or utilizes 4450 B.t.u. instead of 14,400 B.t.u. We used to think that we were saving coal with the dampers shut, but we knew little about carbon monoxide then.

I should avoid cleaning the fires in working hours, preferring to clean them when the mill is stopped. If the fires must be cleaned while the mill is running, I would have one side of the fire burned down; clean the refuse and ashes out clear to the bridge wall; throw the coal from the other side that is unburned; coal that over, and when that is kindled up clean out the other side and coal that up. This insures a clean fire all over the furnace.

We hear a great deal about the great loss from opening the doors when hand firing, but I have not found this to exist. If one will watch the operation of the steam-flow meter, he will find that the horsepower of the boiler does not drop when the fire door is opened.

I have had both doors on a boiler open for one minute and have seen no perceptible difference. The greatest loss comes from the uneven feeding of a boiler with water. I have seen the registration of a meter on a boiler drop from 500 hp. to 250 hp. in one minute, due to the fireman's opening the valve carelessly.

It is very necessary, in order to get economical results either with hand firing or stokers, to keep the boilers and the tubes perfectly clean and to stop all air leaks around the boilers. On our boilers at the Wood Mills we blow the tubes every eight hours — three times in 24 hours, and open up and wash out the boilers every two months — that is, a certain number every week. We have very good water. If the water were bad, we would have them done oftener. I was once found fault with because the men used so many manhole gaskets, but I told the manager that manhole gaskets were cheaper than boiler makers. I never heard anything more about manhole gaskets.

7 *To What Kinds of Plants and Coals Are the Different Types of Mechanical Stokers Respectively Adapted, and What Is the Limiting Factor to Their Use in the Small Plant?*

JOSEPH HARRINGTON.[1] The usual and generally accepted classification of coals from the viewpoint of the mechanical-stoker manu-

[1] Member of Conservation Committee, United States Fuel Administration for Illinois.

facturer and operative is based on the tendency of coal to fuse together upon the application of heat and form a solid mass, or piece of coke, which is impervious to air at ordinary draft pressures. Those coals which act in this manner are called coking coals, and to prevent this cementing action the fuel bed must be kept in agitation during the period when the tarry element is being formed. This feature has limited the field of the chain-grate stoker, and those forms of this stoker which leave the fuel bed entirely quiet have been effectually excluded from the coking-coal territory. For this reason those stokers which agitate the fuel bed and those which supply air under artificial pressure have been found most suitable to these fuels.

The success of the inclined and gravity underfeed stokers has been due in large measure to their adaptability to this particular characteristic of eastern coals.

RECLASSIFICATION OF COALS ON ASH-CONTENT BASIS

Attempts by the manufacturers of this equipment to enter the high-ash and high-volatile regions of the Middle West have developed another significant feature which is becoming all important, and to a large extent is going to supersede the former system of classification. One of the characteristics of middle-western coals is the relatively high ash content. The use of stokers which disturb and agitate the fuel bed has shown in emphatic manner the importance and value of reclassification based on the ash element. This classification may parallel to a large extent that based on the coking qualities of the coal, heretofore regarded as the broadest division. Neither the coking nor the ash features afford a clean-cut and definite line of separation because the coals of the country are of all grades and intermediate qualities, and shade one into another by almost imperceptible gradations. Broadly speaking, there is a very definite difference between the coals found east and west of Pittsburgh.

I would therefore reclassify mechanical stokers along the following lines, and consider this classification as vital in their successful application to the immense territory lying west of the Alleghany Mountains:

While there are many variations in the design of stokers, they all fall into one of two classes: first, those having the grate surface immovable, or non-progressive, the fuel traveling bodily over the grate surface impelled either by purely mechanical means, or me-

chanical means aided by gravity; and second, those having the grate surface movable and traveling at the same rate as the fuel, the latter resting undisturbed thereon. Consideration will show that this is a basic stoker difference and hereafter must be given its full importance or value in assigning a type of stoker to a given region.

As previously stated, coking coals must be agitated during the early combustion stages and it is this which limits the application of the chain grate to the eastern fuels, and not the low ash content, which is also characteristic.

On the other hand, those stokers which naturally and inevitably agitate the fuel get into trouble from this very cause when handling the high-ash western coals.

FUEL-BED DISTURBANCE AN IMPORTANT FEATURE IN STOKERS

Extensive and careful observations impress me with the fact that the fuel-bed disturbance is and must continue to be the most important single element in mechanical stoking. When these fuels are burned at a rate which produces fusing temperatures in the furnace, the ash will either liquefy or soften so as to be sticky and the slightest disturbance will cause it to ball up and form clinkers of immense size. The more it is agitated, the worse this trouble becomes. At rates of combustion which are possible with the underfeed type of stoker a limit is actually reached, and the fire gets into such condition that operations must be stopped to allow the cleaning of the furnace. Even if it is possible to dump the refuse as formed, ashpit conditions become intolerable and it is almost impossible to remove the ash under these conditions. I am becoming convinced, therefore, that the efficiency of the otherwise highly efficient type of stoker which we know as the underfeed or inclined type, is largely offset by the unavoidable ashpit losses and the excessive amount of labor which must be expended in removing the hot ash and clinkers which come from these stokers, and in controlling the side-wall accretions. Observations accompanied by analysis both under test and under ordinary operating conditions show that from 20 to 50 per cent of combustible will be found in the ash, and that this represents anywhere from 3 to 6 per cent of the total coal fired. It is possible to burn such high-ash coals with not to exceed 20 per cent of combustible in the refuse, and when conditions are right 10 per cent can readily be obtained.

I should therefore like to call attention to this fact and suggest that the ultimately successful stoker for the region lying west of

Pittsburgh will be one which does not agitate the fuel, and which discharges the refuse as formed and at the same time does not admit to the furnace more than the usual requirements in the way of air. It is possible to burn these fuels on this type of stoker with the proper amount of air per pound of coal, and when the draft is intensified by mechanical means, rates of combustion in conformity with modern requirements can be developed.

Great stress is invariably laid upon gas analysis, and without question it is a most important index of furnace efficiency. Recent developments, however, have shown another and serious source of loss, which, while it has been recognized, has not been given its proper weight. The ashpit is the source of loss to which I refer and before conservation can properly be carried out, this loss must be largely eliminated.

The answer to the question as to the minimum size of installation which warrants the application of mechanical stokers must be relative and not absolute, since there are at least two variables which enter into this combination.

Any application of mechanical stokers which pays for itself in three years is warranted. Paying for itself may be made up by reduction in the cost of the coal used, in a reduction of the labor required in operation, or both. A stoker will use up its value in fuel three times a year so that it is only necessary to secure a relatively small reduction in the price of coal to show a large profit on the cost of the installation. Labor enters into this proposition almost as importantly as does coal, since the supply of labor is becoming scarce and higher priced every day.

THE FIELD FOR THE MECHANICAL STOKER

The great thing, however, for the country to consider at present is the opportunity which undoubtedly exists to burn lower grades of coal in a fairly economical manner, by the use of proper stokers, than can be burned in the hand-fired furnace. Coal which ordinarily would be classed as refuse, containing 40 per cent in ash, 7 per cent in sulphur and 15 per cent of moisture as fired, is being successfully burned in more than one plant.

It would be practically impossible to develop rating by hand-firing this fuel. If, therefore, the small hand-fired plant ordinarily accustomed to burning a good grade of lump or sized coal can secure a supply of screenings, even though they be of a low order, and provided they can be purchased at a reduced price, it can well afford

to install a mechanical stoker. It is recognized that the small stoker costs out of proportion to its active grate area, but at the same time the percentage in saving may be greater than in the case of the larger installation because the fact remains that the small installation is usually the worse offender from an economic standpoint.

Authentic cases of 25 to 30 per cent reduction in the cost of coal abound when this change has been made. From a theoretical standpoint, at least, there is no minimum limit in the practical size of steam boilers suitable for the application of mechanical stokers. Merely because stoking has been developed with the larger units is no reason why it should not be developed for the smaller unit, and in consideration of the large percentage of the total fuel supply that is consumed in the very small plant, it is imperative that engineers give this phase of the question their earnest consideration. If the stoker does not exist which is suitable for a 50- or 75-hp. boiler, it must be developed, and my prediction is that it will soon appear on the market in perfected form.

The answer, therefore, to this part of the question is literally that there is no minimum limit to the size of boiler adapted to the use of a mechanical stoker; but interpreting the question as it will ordinarily be interpreted, my opinion is that anything over 150 hp. becomes a possible field for the application of the stoker.

J. Van Brunt. The selection of mechanical stokers with regard to coal and size and character of plants presents a problem that can only be answered in each individual case, and the proper solution can be reached only when all of the factors entering into the problem are known.

It is hardly advisable to arbitrarily classify plants, stokers and coal and attempt to predetermine on the basis of such classification the proper mechanical stoker. For the purpose of discussion, however, stokers and coals may be classified, and in a general way plants may be divided in four classes: Underfeed stokers; traveling or chain grates; overfeed stokers; and miscellaneous, such as powdered-fuel burners, shovel or scatter stokers, and semi-mechanical grates.

CLASSIFICATION OF STOKER PLANTS

Underfeed stokers are again subdivided into multiple retort, as the Riley, Westinghouse and Taylor; single retort with dead grates (Jones); and single retort with inclined moving grates, as the Type E. Chain or traveling grates are of two types, differing principally in

the fuel-bearing surface. In the chain grate the grate surface is composed of a large number of links held together by through bolts making a broad band of endless chain on which the fuel is carried. The traveling grate, on the other hand, consists of a number of grate bars or sections of grate bars held on cross-members, which in turn are fastened to the driving chains at either side of the stoker. The chains are thus below the fire line, and not subject to the heat as in the chain grate. There is a further division of such grates in forced-draft and natural-draft grates. Overfeed stokers may be front feed as the Roney or side feed as the Murphy and Detroit. The semi-mechanical grates and miscellaneous stokers need hardly be described further.

Coals present such a wide range of qualities aside from their approximate analyses and heating values that it is difficult to present a satisfactory classification.

TYPES OF BOILER PLANTS

Boiler plants for the purpose of this discussion may be divided into four general classes, as follows: First, low-pressure heating plants of one or two smaller boilers, including such small high-pressure plants of similar size as are found in some office buildings and factories where the load is small and the boiler set so low that a satisfactory stoker installation is impossible except at prohibitive expense; second, moderate-sized plants having ample boiler capacity operating at moderate ratings, and not requiring additional capacity; third, industrial plants of large and moderate size, requiring additional boiler capacity, where the labor may be materially reduced by stokers; fourth, central stations or plants having the characteristic load curve of such stations.

ADAPTABILITY OF STOKERS TO DIFFERENT REQUIREMENTS

In the first class of plants stokers are not, as a rule, adaptable to low-pressure boilers because of the fact that power is required to drive the stokers; and no saving in labor is possible, nor can stokers usually be installed except at considerable expense for changing the boiler setting or lowering the floor to secure sufficient height or distance between fire and shell or tubes of boiler. This latter condition also applies to high-pressure plants of similar character.

In the second class the use of stokers would depend on the labor and coal saving possible. The load conditions and the coal available will determine the type of stoker. For steady, moderate

loads and high-ash coal the chain grate will be satisfactory; for some load conditions and good coal, the overfeed type. The underfeed type will also be satisfactory under most conditions, particularly where the coal is likely to vary in quality from time to time.

For plants falling in the third class, the forced-draft underfeed stoker will generally be found to be the most satisfactory because of its great flexibility, overload capacity and high furnace efficiency over a wide capacity range. This type of stoker will handle practically all coals between and including semi-anthracite and sub-bituminous with an ash content up to 15 per cent, and, except for high continuous overloads, 20 per cent.

For free-burning coal of higher ash content than 20 per cent, the forced-draft traveling grate would be a satisfactory equipment, assuming that adequate provision is made to handle the ash.

Central stations and similar plants in the fourth class are practically forced to use underfeed stokers. Because of the low load factor of such plants it is essential that the stokers be able to force the boilers up to high overloads — 250 to 300 per cent of their rating for the comparatively short peak loads. It is also necessary at times to meet extraordinary loads with but little warning, and for this purpose the forced-draft underfeed stoker, because of its elasticity, is not equaled by any other stoker.

Starting from a banked fire with an underfeed stoker, it is possible to bring a boiler up to 200 per cent of rating in from four to six minutes, a performance not possible with any other type of stoker.

Where the coal has a high ash content and is of low heating value, it may be advisable to use traveling grates with forced draft. Sufficient grate surface can usually be provided to take care of the required overloads. This type does not respond as quickly as the underfeed type to sudden load changes, but where peak loads occur at certain known times they can readily meet such conditions.

So far the fuels considered have been those between and including semi-anthracite and sub-bituminous.

The successful use of mechanical stokers for burning the finer or steam sizes of anthracite is a comparatively recent development, and the writer considers himself fortunate in having been closely associated with this development. These fuels and coke breeze are now burned successfully on a traveling-grate stoker with forced draft. This stoker is the development of the work and experiments of the late Eckley B. Coxe, a prominent anthracite-coal operator.

Many boilers equipped with these stokers and burning No. 3 buckwheat coal or coke breeze are being operated at from 150 to 200 per cent of rating. Because of the cost of the equipment it is not usually advisable to install in small plants or small boilers where only moderate loads are required.

This type of stoker is not as elastic as the underfeed, but is more so than the natural-draft chain grate. It would probably not meet satisfactorily the conditions of violently fluctuating loads.

Some recent experiments on this stoker have indicated the possibility of burning as high as 60 lb. of bituminous coal per square foot of grate, and in the near future there will be more data available on the burning of Illinois coal and lignite on this grate.

In existing plants among the principal limiting conditions found are the setting heights of boilers, the capacity of the breechings and stacks, the overload requirements, the kind of coal, the class of labor and the cost of the installation, and the foregoing classification of plants is only an attempt to generalize.

Thomas A. Marsh. The two general classifications of fuel from the standpoint of adaptability to stokers are: (1) coking and non-coking; (2) clinkering or non-clinkering. Compared with these characteristics all other properties sink into insignificance, as every experienced fuel burner knows. The writer would therefore discuss the stokers suitable for each of these classifications.

Coking coal is coal whose tars fuse at a temperature below their distillation point, resulting in binding the fuel together in a caked mass. Obviously, such a fuel-bed condition must either not be allowed to occur or it must be broken up soon after occurring. Stokers suitable to such fuels are underfeeds, inclined stokers similar to Murphy stokers, Roneys, L-type chain grates, Type E stokers. Almost all such fuels are found east of Pittsburgh, although some coking fuels are found in a few western sections.

Non-coking coals are those whose tars distill off at a temperature below their fusing point. Such coals are, therefore, obviously free-burning. The chain grate is most suited to these coals. The performance of the Commonwealth Edison Co. of Chicago is well-known and striking evidence of this fact. Such fuels comprise most of the fuels of Ohio, Illinois, Indiana, Iowa and in general all coals west of Pittsburgh. Those types of stokers which do not agitate the fuel bed give best results when the coal is free-burning. A characteristic of such stokers is the minimum of operating attention

necessary and the uniformity of results obtainable with minim attention. Bituminous coals above described are being burned 14 per cent CO_2 with 3 to 5 per cent ashpit loss. Combustion ra are from 30 to 50 per sq. ft. per hr., and 200 to 300 per cent rati is now common practice, with efficiencies of from 72 to 77 per ce

Clinkering coals are those whose ash fuses at or below 2500 d fahr. Such fuels must be handled on stokers which clear themsel

TABLE 12 COALS SUITABLE FOR VARIOUS TYPES OF STOKERS

LOCATION OF MINE.	ANALYSIS							TYPE OF STOKER	REMARKS.
	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	SULPHUR	B.T.U.	FUSION TEMP.		
Cambria Co., Pa.	3.6	20.3	68.6	7.5	.88	13710	2179		Very bad Clinkers.
Fulton County, Ill.	15.0	33.1	34.8	15.1	2.82	9680	2189		Clinker Trouble at Dump Grate, side Not protected by Steam Jets
Westmoreland Co., Pa.	2.0	35.2	50.0	12.8	2.37	13418	2423		Bad Clinkers.
Raleigh Co., W. Va.	4.2	19.9	70.8	5.1	0.89	14016	2259		Some Trouble with Clinkering and bridging over Dump Grates.
Sunderland, N. Sc.	7.2	38.0	49.8	5.7	1.15	13047	2297		Forms small Brittle Clinkers.
Raleigh Co., W. Va.	2.0	17.9	72.5	6.9	0.92	15899	2309		Trouble with Clinkers Bridging Dump Plates and on Side Walls
Caryville, Tenn.	4.0	35.8	47.4	12.0	1.37	11800	2304		Hard Clinkers.
Raleigh Co., W. Va.	4.4	17.5	70.3	7.8	0.86	15480	2306		Very large Clinkers on Side and Bridge Walls
Cambria Co., Pa.	1.9	25.3	64.7	8.2	.38	13770	2322		Some Trouble from Clinkers.
Cambria Co., Pa.	2.4	19.9	69.9	8.1	1.30	13847	2361		Very Bad Clinkers.
Westmoreland Co., Pa.	2.4	33.0	51.7	10.7	1.87	12718	2384		Bad Clinkers.
Mercer Co., Pa.	3.4	34.0	47.5	15.1	3.40	12291	2380	Taylor	No serious Clinker Trouble.
Bear White, W. Va.	2.4	17.7	72.8	5.3	0.72	14113	2384		No Clinker Trouble.
Pocahontas	4.2	17.8	72.1	6.1	0.66	13918	2435		No Clinker Trouble.
Fayette & Raleigh Co., W. Va.	1.4	22.0	71.8	4.7	1.11	14366	2408		Large Clinkers on Side and Bridge Walls
Somerset Co., Pa.	1.0	17.7	70.6	10.8	2.14	13889	2414		Good Coking, Free Burning, Forms Large Extreme Clinkers
Pittsburgh District	3.4	35.4	54.3	10.9	1.93	13006	2427		Very Little Trouble with Clinkers.
Cambridge, Ohio	8.0	37.7	48.5	9.0	2.75	12587	2436		Forms Thin Brittle Clinkers.
Somerset Co., Pa.	0.8	17.6	71.6	10.0	1.96	13501	2468		Forms Large Clinkers.
Cambria Co., Pa.	2.2	36.4	53.2	8.2	2.07	15208	2534		Slight Clinker Trouble above 200% Rating.
	1.5	20.4	68.5	6.6	1.97	14030	2554		No Clinker Trouble.
Glen Richie, Clearfield Co., Pa.	2.1	34.1	54.6	9.0	1.81	13480	2686		No Trouble.
Cambria Co., Pa.	1.8	33.4	56.7	7.5	1.36	14003	2694		No Clinker Trouble.
Washington Co., Allegheny Co., Pa.	0.3	33.2	57.1	10.4	1.06	13280	2390	New Roney	Bad Clinkers.
Washington Co., Pa.	3.7	37.7	58.7	12.4	1.46	12340	2363		" "
Rock Springs, Wyo.	4.8	35.8	44.3	15.1	1.84	11285	2329		Very Thin Soft Clinkers, gives serious Trouble
Barnesboro, Cambria Co., Pa.	2.6	33.4	56.4	7.6	1.78	13926	2379	Roney	Clinkers part of the Time.
	3.6	34.1	55.5	8.8	1.61	13414	2430		
	3.2	37.4	56.0	8.4	1.68	13690	2444		
Glen Richie, Clearfield Co., Pa.	2.1	34.1	54.6	9.2	1.81	13480	2481		No Trouble.
Barnesboro,	2.4	33.4	56.4	7.8	1.72	13928	2378	Westinghouse Under Feed	Clinkers part of the Time.
Cambria Co., Pa.	3.6	34.1	53.2	9.0	1.61	13414	2430		
	3.2	33.7	56.0	9.1	1.99	13618	2444		
Westmoreland Co., Pa.	3.2	35.2	50.0	12.8	2.37	13418	2323	Riley	Bad Clinkers.
	2.0	35.0	51.7	10.7	1.87	12713	2384		" "
Glen Richie, Clearfield Co., Pa.	2.1	34.1	54.6	9.0	1.81	13480	2481		No Trouble.
Washington Co., Pa.	0.3	32.2	57.1	10.4	1.06	13282	2390	New Horsfall	Bad Clinkers.
Allegheny Co., Pa.	4.0	32.5	53.3	11.4	1.40	13604	2360		Only a Little Trouble from Clinkers.
West Virginia	1.4	18.5	74.0	5.9	0.84	14468	2379	Murphy	Clinkering Fair—[illegible] Furnace Temp. [illegible]
Fayette Co., W. Va.	1.2	17.6	76.2	5.0	0.54	14897	2471		Very Little Clinker [illegible] " " " [illegible]
Wood Co., W. Va.	1.4	33.8	55.7	7.1	0.55	13851	2500		Good, no Clinkers—[illegible] " " " [illegible]
Illinois	8.8	34.0	39.4	17.8	3.10	10291	2092	Chain Grate	Lots of Clinker, but very Little Trouble
Madison Co., Ill.	12.0	36.0	38.4	13.6	4.36	10147	2091		
Illinois	9.8	34.4	38.1	17.7	5.0	10739	2187		
Christian Co., Ill.	13.6	30.8	37.8	17.8	3.24	9681	2179		Plenty of Clinkers, but no Trouble—[illegible]
Sangamon Co., Ill.	14.2	31.4	38.5	15.9	4.40	9718	2179		" " " " " " "
Illinois	9.0	35.2	45.7	12.1	1.98	11869	2203		Lots of Clinkers, but very Little Trouble
Vigo Co., Ind.	10.2	33.8	38.4	17.6	3.28	10291	2256		Plenty of Clinkers, but no Trouble—[illegible]
St. Clair Co., Ill.	10.8	35.4	37.8	16.0	2.04	9910	2329		Lots of Clinkers, but no Trouble
Saline Co., Ill.	8.8	31.8	50.5	10.9	3.34	12020	2397		Plenty of Clinkers, but no Trouble—[illegible]
Cambria Co., Pa.	2.0	33.4	56.4	7.6	1.75	13926	2379		Clinkers part of Time
Barnesboro,	2.8	34.1	53.5	9.0	1.81	13414	2430		
	3.2	33.7	55.0	8.1	1.99	13618	2444		
Carthage, N. Y.	1.2	37.8	45.0	15.8	1.01	10195	2081		No Clinker Trouble.
Cambria Co., Pa.	1.2	30.9	58.3	9.7	2.48	13800	2468	Hand Fired	No Clinker Trouble.
	1.6	33.9	56.0	8.5	1.97	13928	2341		
	1.4	35.9	57.0	6.8	2.08	13906	2370		
Somerset Co., Pa.	2.4	16.8	71.0	9.8	1.83	13440	2347		
	2.4	16.4	70.9	10.6	1.97	13280	2394		

of ash continuously. If the coal in question is a coking coal, t fuel bed should be agitated. If, on the other hand, the coal is fr burning, the fuel bed should not be agitated, as this simply agg vates the clinker trouble.

The work of the late J. P. Sparrow has been particularly help in aiding in the selection of suitable coals for certain stokers wh a choice of coals is possible, and in the selection of suitable stokers the available coal where a coal selection is not possible. Mr. Sp

row's tabulation of a variety of coals as presented before the National Electric Light Association in 1916 is given in Table 12.

The ash of most of the middle-west and western coals fuses from 2000 to 2400 deg. fahr. and some as low as 1800 deg. Clinker accumulations must be avoided. There are two methods of doing this. One is not to make the clinker, which necessitates that the ash be kept on the lower stratum of the fuel bed and out of the high-temperature zone; the fuel bed must not be agitated. The other method is to have a continuous discharge of the ash from the furnace.

The chain grate, which embodies both of these principles of keeping the ash on the low-temperature stratum of the fuel bed and of discharging the ash continuously from the furnace, is suited

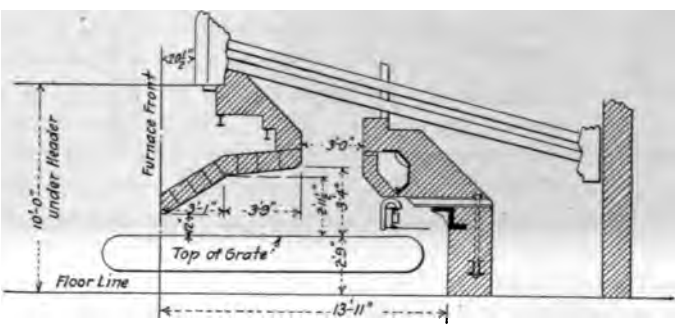


FIG. 14 CHAIN-GRATE SETTING FOR LIGNITES AND HIGH-MOISTURE COALS, 7000 B.T.U.

to coals of the northern interior, eastern interior, Gulf, western interior, southern and Rocky Mountain fields.

Suitable stokers for coal that cokes and also clinkers are Green "L" type, Murphy, Model and Detroit.

In the West we have many lignites and high-ash coals containing from 7000 to 9000 B.t.u. In localities where these are found such fuels are not the occasional ones, but are used day in and day out. These coals are handled very well on chain grates. Figs. 14–16 show some of the furnaces used for such fuels.

Fig. 14 shows a design of furnace in connection with a B. & W. boiler suitable for burning low-grade coals. This furnace was used with lignite coals having an analysis as follows:

Moisture	39.94	Fixed carbon	26.44
Volatile matter	30.95	Ash	11.66
B.t.u. as fired	7124		

This very low-grade fuel was burned at a combustion rate of 31 lb. per hour per sq. ft. of grate surface and developed a combined boiler and stoker efficiency of 71.3 per cent.

Figs. 15 and 16 show the types of furnaces used for burning high-ash coals. A typical analysis of one of these coals is as follows:

Moisture	14.92	Ash	25.38
Volatile matter	28.54	Sulphur	4.73
Fixed carbon	31.16	B.t.u. as fired	8117

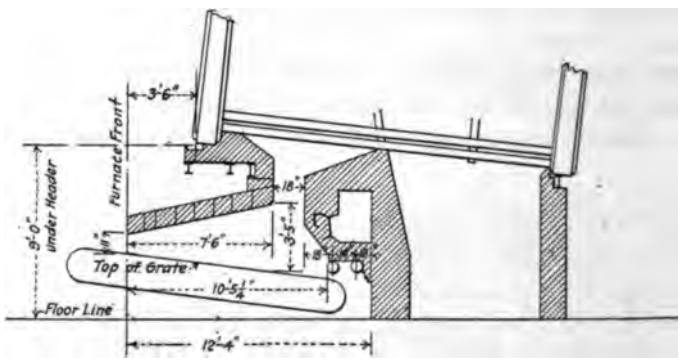


FIG. 15 CHAIN-GRATE SETTING FOR HIGH-ASH COALS, 8000 B.T.U.

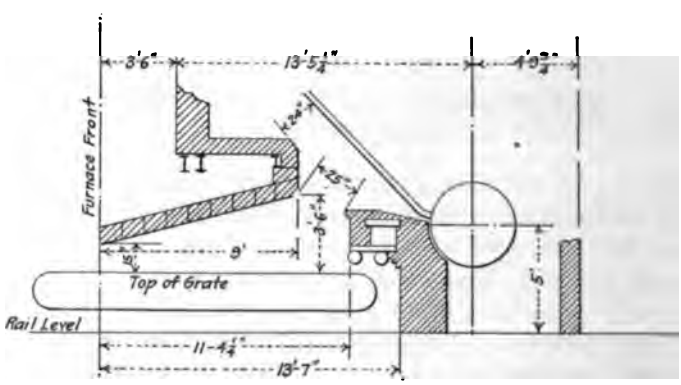


FIG. 16 CHAIN-GRATE SETTING FOR HIGH-ASH COALS, 8000 B.T.U.

Furnaces as shown in Figs. 15 and 16 will burn such coals as this at efficiencies from 72 to 75 per cent and with combustion rates of 35 to 40 lb. per hour per sq. ft. of grate surface.

Suitable stokers for free-burning clinkering coal include all chain grates and traveling-bar stokers. The argument in favor of this type of stoker is very strong, due to higher operating efficiencies,

low labor cost and low maintenance cost against the reverse if agitating stokers are selected.

Suitable stokers for coking, non-clinkering coals are: Underfeeds, "L" type chain grates, Murphy, Model, Detroit and similar agitating grates. Such coals are New River, Pocahontas and the better-grade eastern fuels.

These are broad classifications. Local operating conditions may occasionally indicate exceptions to these selections.

We should not in our entire discussion of this problem lose sight of the commercial aspects of labor saving, ease of operation and maintenance of furnaces and continuity of service when stokers are using unsuitable fuels.

CARL SMERLING. The hand-operated stoker is now installed in all types of furnaces and almost every type of boiler from 40 to 600 hp. in one unit, and to the extent of 5000 hp. in one fireroom. This stoker could well be named the Ford of stokers, or more closely nicknamed the "Jitney."

I have no reason to believe that the hand stoker will ever be adopted or used extensively in any large power plant or central station, but believe that its place belongs in the smaller units of 500 hp. and below. These stokers are now in use under oil stills, oil-cracking furnaces for the production of gasoline, and acid furnaces, and in concentration furnaces, hot-mill and annealing furnaces.

HAND-OPERATED STOKERS

The principal objects of this stoker are to obtain a more universal and complete combustion, increasing the efficiency of the boiler, and to reduce labor, thus eliminating carelessness on the part of the fireman, which is accomplished in doing away with the cleaning of fires by the old method, and by the coking method in which the coal is piled high in front of the fire doors.

To facilitate the advancing of fire, crushing of clinkers and the maintaining of a continuously clean fire, it is necessary that the stoker bars rise in alternate movement to a perpendicular position, thus crushing the clinkers from the width of two stoker bars to the width of one (or from 12 in. to 6 in.).

To prevent the loss of coal when the stoker bar is in a perpendicular position, the bar should have a circular shield or apron which causes the space between the bars to remain constant. This shield should be perfectly smooth, without holes or indentations, to prevent

clinkers from catching or binding, thus allowing the bars to fall back in their original position.

Thus sifting out the ash from the clinkers, the stoker finally deposits approximately 5 to 8 per cent of the total ash in clinkers at the bridge wall on the dump grate, where it is dropped at regular intervals as required. If red coke falls through the grate, it is an indication that the fireman must not pull the levers more but wait until the ashpit again looks a little dark. This pulling of levers as a rule requires one pull of each lever every half-hour, and on the average coal of 12 per cent ash the dump grate should be dropped once in 8 hr. After continuing this operation, it is possible to run water-tube boilers up to 225 per cent rating without difficulty, provided sufficient stack and correct flues are installed; at 175 per cent rating it is not unusual to obtain 72 per cent combined efficiency and a continuous high CO_2 of an average of 13 per cent.

One of the most interesting features of this "Jitney" stoker is the fact that the first cost of installation is very low compared with the saving over that of hand-fired flat or shaking grates.

Robert H. Kuss contributed the data given in Table 13 on the types of plants and qualities of coal for which stokers of different types are adapted.

TABLE 13 COALS AND PLANTS TO WHICH VARIOUS STOKERS ARE ADAPTED

Type of Stoker	Minimum size of unit, hp.	Minimum plant, hp.	Maximum size of unit, hp.	Best Coal Characteristics	Unfit Coal
Traveling grate	200	600	600	High volatile	Coking and low-ash
Underfeed, Jones	150	300	300	Medium volatile	High-ash, low-fusing ash
Combustion Engrg. Corp., Type E	150	300	250	Medium volatile	High-ash, low-fusing ash
Single incline	200	600	400	High fixed carbon	Low-fusing ash
Double incline	200	400	350	Medium volatile	Low-fusing ash
Inclined underfeed	500	2000	Any larger size	High fixed carbon	Low-fusing ash

P. W. Thomas. The stoker is restricted to a coal containing an ash which it will scavenge cleanly and without injury to its own metal. This brings a sharp division in the present types of stokers. Where the coal fluxes its ash at furnace temperature, a chain grate will

invariably give the highest operating efficiency. Where the ash content is under 5 per cent or where it will not flux at a temperature above 2600 deg. fahr., other types of stokers will give the same efficiency if properly handled.

The limiting factor in the use of the stoker in small plants is the cost of labor.

There is no *type* of fuel in the United States. Each field and each coal-producing district has absolutely individual fuel. The only comparison by analysis of the various fuels must be that analysis which shows, in addition to the usual proximate analysis, the quantitative analysis of the ash and its fluxing temperature. Given these figures, it is a matter of simple calculation to know which of the many stokers will perform so as to supply the greatest percentage of heat to the boiler.

By the above let me explain that two bituminous coals showing the same proximate analysis may have entirely different ash contents, entirely different coking properties and attendantly different combustion rates. They both require the same quantity of air in the consumption of a pound of coal, but no device will cause one coal to unite with its given quantity of air in a shorter interval of time than its nature allows. The flexibility of a stoker, then, depends on how many pounds of coal can be supplied with the proper amount of air at one and the same time. Two methods are open: to increase the grate surface, or thicken the fire and apply the forced draft. In the latter case it is again necessary to figure the fluxing temperature of the ash in incandescent coke.

WALTER E. BRYAN. It has been common practice with Illinois fuel, where mechanical stokers are desired, to use chain grates. These give very satisfactory results, except that they cannot be forced to any great extent. Underfeed stokers should have a little larger size of coal, and also coal freer from impurities than that required for the chain grates. Stokers of the Westinghouse type have recently been used in this district on bituminous screenings with great success.

B. J. DENMAN. The chain-grate stoker is best adapted to coals containing 25 per cent or more of ash, due to the facility with which it disposes of the refuse. This is one of its chief advantages, and in addition to this it is one of the cheapest stokers available, and undoubtedly has the lowest cost of maintenance. From the operating

standpoint the chief objections to the chain-grate stoker are its lack of responsiveness and the fact that its point of best efficiency is rather sharply marked, dropping off somewhat rapidly at overloads and very rapidly at light loads. With proper care, good efficiencies can be maintained within a reasonable range of capacity, the low percentage of CO_2 which is obtained in most plants being unnecessary. The chain-grate stoker is practically smokeless. To secure the best results it should be set with flat coking and boiler arches of an inclination and length to best suit the fuel burned. The stoker is suitable for non-coking coals only. With coking coals it is impossible to get reasonable capacity, and the ash is practically pure coke. Chain grates which have been designed to burn coking coals have not been found to be successful.

The inclined overfeed type of stoker has the advantage of reasonably low cost but the disadvantage of high maintenance. Most stokers of this type require frequent poking of the fires, which produces considerable smoke. These stokers are not suitable for coals containing over 15 per cent of ash. They have a limited range of capacity, but are quite responsive to change in loads.

The inclined underfeed type of stoker has the greatest range of capacity, the best efficiency of any stoker available, and the additional advantage that it is the most responsive to changes in load. Boilers can be raised from banked fire to steaming at the rate of 200 per cent in less than five minutes. This type of stoker has an unusually flat efficiency curve, with a high efficiency throughout the range, and with most arrangements of settings the highest efficiency is at light loads. This applies particularly to coal averaging about 14,000 B.t.u. and from 6 to 8 per cent ash. This enables a plant having evening peaks to eliminate the carrying of banked fires to meet the peak load, as it is possible to install sufficient stoker capacity to secure a boiler rating of 300 per cent.

The chief disadvantage of this type of stoker is its high first cost, but this is offset by the high capacities possible, which reduce the boiler-room investment. It is, of course, undesirable to operate the boilers at such high rating except for short periods, and for plants having no short peaks it would be uneconomical to put in sufficient stoker capacity to obtain these peaks. It has been my experience that considerably higher combined boiler and furnace efficiency can be obtained with this type of stoker than with any other type, and I have made extensive tests with chain-grate, inclined overfeed, and inclined underfeed stokers. This stoker is suitable for coals having

as high as 20 per cent ash, but with coals running this high in ash, and with heating value as low as 10,000 B.t.u. per lb., it is necessary to arrange dumping sections of about twice the length normally provided and to increase the height of the stoker sufficiently beyond the amount usually required, if very high rating is desired. We are carrying loads as high as 300 per cent rating with Illinois coal averaging about 10,500 B.t.u., with 15 per cent ash. The maintenance of this type of stoker is low as at present designed. This stoker is suitable for either coking or non-coking coals.

I do not believe the size of the plant determines whether or not a stoker should be used. This is more a question of labor conditions, load factor and funds available. We are at present operating a plant containing three 500-hp. boilers, hand-fired, while in an adjoining city of practically the same size we found it advantageous to install stokers. In that same city we are operating a gas plant containing two 200-hp. boilers, only one of which is in use at a time, which we have equipped with stokers.

A. H. Blackburn. For the large electric-power plants with wide ranges of coal, and the larger manufacturing plants with boiler units from 500 to 2500 hp., the underfeed gravity and underfeed direct-push, self-cleaning stokers are the types of stokers best adapted, because they respond most quickly to the varying coals. They will show high efficiency for a range of from 80 to 200 per cent of rating. They will raise steam from no load to 200 per cent in a few minutes and are practically smokeless. They will successfully burn Pennsylvania, Maryland, Virginia, Ohio, Kentucky and Michigan coals.

The chain grates show best results when working at a steady load. They are adapted to free-burning coal high in volatile such as the coals mined in the Middle West; they are not so suitable for the coking coals having high fixed carbon.

The overfeed, inclined-grate and the side-feed stokers are adapted to boilers from 150 to 300 hp., and obtain their best economy when working from 80 to 100 per cent of rating and are not suited to heavy overloads.

The underfeed stokers and the combination of underfeed and overfeed stokers are suitable for boilers from 150 to 500 hp. and show excellent efficiencies at ratings from 80 to 150 per cent and can be worked up to loads of 200 per cent. The advantages of these stokers are the rapidity with which they will take care of sudden variations

in load, the average good efficiencies obtained, and the comparatively low cost of repairs. They will successfully burn coals from Illinois, Kentucky, Ohio, Pennsylvania, Maryland, West Virginia, Iowa and Michigan. For internally fired Scotch marine boilers and internally fired vertical boilers of the Manning type the underfeed stoker has been successfully applied, showing results of 10 per cent saving over hand firing.

For the fair grades of lignite coals of the West the underfeed stoker is being used with considerable success, especially when the fuel comes directly from the mine and before it dries out, by running light fires and rapid combustion.

As to the limiting factor in the use of mechanical stokers in small plants: Stokers can be applied with good results to boilers as low as 100 hp., especially when there is only one man employed to look after the boiler, engine and other apparatus about the plant, as hoppers can be put on that will hold an hour's supply of coal, or more; the automatic regulation will take care of the steam or combustion rate while the attendant is looking after other work.

WILL SUCCESSFULLY BURN GREEN LIGNITE

Stokers have too often been applied under unsuitable conditions. Proper consideration has not been given to combustion space, the size of the unit and the particular design of the boiler to which the stoker has to be applied. The time has come when the first consideration must be given to proper design of combustion area to the particular quality of coal to be burned, and to the installation of boiler and stoker designs best suited to this condition.

Wm. M. Park. Most of my experience with stokers has been with the chain grate, but I have carefully observed the operation of underfeed stokers for periods of two to three months at a time in several different plants and with a variety of coals. The efforts of underfeed designers recently have been concentrated on means of securing continuous ash discharge, which is an inherent feature of the chain grate and not recognized by the earlier designers. The effort along this line has met with fair degree of success in burning low-ash coals having high-fusing-temperature ash.

Conclusions based on what I have seen limit the underfeed stoker to the burning of coals containing not over 15 per cent, and preferably not to exceed 10 per cent, ash. It is also desirable that the ash shall not fuse at a temperature below 2200 deg. It is only

east of the Ohio-Pennsylvania state line that such coals are obtained in abundance for power-plant purposes without special treatment. West of that line the purchaser of underfeed stokers should be prepared to purchase only high grades and consequently higher-priced coals, usually held for domestic and locomotive uses. In some districts washed coals of suitable grade are available, but the amount is limited and the price generally higher than crushed run of mine from the same source.

While the above conclusions indicate my preference for stokers that can employ relatively thin fires and an unagitated fuel bed for high-ash coals, I do not feel that they are unadapted to burning low-ash fuels. As many of the low-ash coals have a tendency to coke, it is desirable that the stoker have provision for agitation during the early stage of combustion where the coke-forming hydrocarbons are

TABLE 14 RELATIVE CAPACITY AND EFFICIENCY OF 822-HP. STIRLING BOILER WITH CHAIN GRATE

Per Cent of Boiler Rating Developed	Combined Efficiency of Boiler, Furnace and Grate, Per Cent
80	77.9
100	77.4
120	76.4
140	75.3
160	73.8
180	72.0
200	69.7
220	67.0

being distilled. After this stage it is desirable that the fuel bed be undisturbed so that a layer of ash can form protection to the metal parts of the grate surface.

That the chain grate can meet these specifications satisfactorily and with good results and reasonable maintenance cost is indicated by the number of successful installations of coking-coal chain grates now in operation in those districts which receive the coals of Western Pennsylvania, West Virginia and Ohio. Table 14 gives figures on the capacity and efficiency obtained in tests on one of twenty large units installed at a large power plant in western Pennsylvania. The boiler is an 822-hp. Stirling with a chain grate of 168 sq. ft. area and designed to meet the above specifications. This plant ordinarily operates with natural draft, though provision is made for forced draft to handle peak loads. The forced-draft fans are driven by steam turbines and the total steam used by the fans and stokers

amounts to only 0.4 per cent of the steam generated when operating at rated capacity.

The boilers are readily operated up to 160 per cent rating on natural draft provided by a stack no higher than would be required to remove the gases without nuisance were the plant equipped with underfeed stokers. As forced draft is used only at time of peak load, the power consumption of fans becomes negligible when compared with the average output of the boilers. Therefore Table 14 represents practically *net* efficiencies at various ratings and this point should be borne in mind when comparing its figures with any tests of stokers that use forced draft continuously. The generating unit which operates at the highest "combined efficiency of boiler, furnace and grate" is not always the unit which produces steam at the lowest unit cost, as the steam consumption of draft equipment may reduce the net efficiency to a figure three or four per cent below the test-code item of combined efficiency.

8 *What Experience Have You Had in the Use of Wood as Fuel? To What Extent Is Wood Available as a Fuel?*

Robert H. Kuss. The writer's experience includes the burning of wood refuse coming from kiln-dried manufacturing operations of both hard and soft wood and "hog stuff" produced at logging mills in northern Minnesota. Kiln-dried wood refuse when burned alone constitutes no particularly difficult problem. If a sizable proportion is sawdust or planer shavings, this material must be burned in a complete firebrick furnace, the fuel being introduced by gravity, and most of it being burned in suspension with very little air from the ashpit.

Where coal and wood refuse are burned together, difficulty is encountered if the major portion of the fuel is sawdust. Planer shavings in large quantities set up extremely difficult conditions. In any event, the combination of fuels must be burned in a complete firebrick furnace, so that the sawdust portion may be burned in suspension.

When "hog stuff" is produced from bark, edgings, etc. (as is the case in lumber-producing mills), it is best burned in a complete firebrick furnace where the fuel is introduced so as to form cone heaps over the grate surface, very little air being introduced by way of the ashpit, and the fire being most brisk at the grate surface around the edges of the cones.

ALBERT A. CARY. I have had to handle wood as a fuel under a wide variety of conditions which have called for different constructions in furnaces, as wood from a lumber camp, where undesirable tree trunks, boughs and branches were burned; in saw mills where the fuel was slabs, edgings and sawdust; in wood-pulp mills where the wood refuse was burned; in woodworking establishments where the fuel was the refuse from the saws, planers and other woodworking tools.

It must be remembered that fully one-half the weight of the wood is found in the volatile gases passing off during the process of combustion. With properly designed furnaces, the greater part of the air required for the combustion of these gases can be made to pass through the grates and fuel bed, where they become warmed to such an extent that they will not suppress the combustion of the gaseous portion of the fuel in the combustion chamber. An ample and well-designed combustion chamber is also essential to obtain efficient results.

Two objections commonly offered to the use of wood fuel are the production of objectionable smoke and danger from fire due to burning firebrands ejected from the chimney. With a properly designed and operated wood-burning furnace, however, the smoke nuisance can be so reduced as hardly to constitute a nuisance, and I have found no difficulty in stopping the trouble from sparks and hot cinders by using cinder screens enclosing the top of the chimney.

HEATING VALUE OF WOOD FUEL

In the boiler-test code of the Society we have been instructed to regard 1 lb. of wood as equivalent to 0.4 lb. of coal; or, in other words, 2½ lb. of wood are equivalent to 1 lb. of coal.

The value of *dry* wood used as a fuel may be slightly greater or considerably less than this equivalent of bituminous coal, according to the design of the furnace used and the manner in which the fire bed and its air supply are handled. The percentage of moisture carried materially affects the heating value of wood fuel, and therefore it is most desirable to have the wood as dry as possible.

Wet fuel, however, must often be used, and I have burned pulpwood chips or shavings running as high as 30 to 40 per cent in moisture. Such very wet wood fuel must be burned in a reverberatory furnace with a heavy bed of burning fuel maintained, to dry the moist wood rapidly as it is fed continuously into the furnace.

Newly cut wood contains a large percentage of moisture, which

varies in the different varieties of wood, but from one-third to one-half of this moisture will disappear if the wood is air-dried from six to twelve months.

EXAMPLES OF SUCCESSFUL WOOD-BURNING FURNACES

In burning forest wood such as trunks, boughs and branches, I have found that much better results could be obtained with a wide furnace than with a long, narrow furnace in which wood is charged lengthwise through a front opening. With the long furnace it is difficult to maintain a good level fuel bed and have the grates evenly covered. I have obtained the best results for such fuel with a furnace about 5 ft. wide and 7 ft. deep. This had a charging door, running across the width of the furnace and about 12 in. high, which lifted vertically above the dead plate along the outer face of the front wall, being counterweighted and properly balanced; this door was perforated with a number of ½-in. holes to admit and evenly distribute small streams of air over the fire bed.

The cut lumber was piled in front of the door so that it lay lengthwise, running from one side wall to the other. When the door was lifted the lumber, thus arranged, was pushed over the dead plate on to a grid of sloping grate bars dropping downward at an angle of about 30 deg. At the lower end of these sloping grates and about 18 in. from the bridge wall, I arranged another grid of sloping bars, dropping down from the bridge wall at an angle of 45 deg., thus forming a V-shaped grate surface having a long and short leg.

With this arrangement the lumber was rolled or shoved down the bars from the dead plate in such a manner as to maintain a fairly thick and more or less compact fire bed over the lowest position formed by these sloping grates, and very little difficulty was found in keeping the upper end of the grates (nearest to the door) covered with fuel. The charging door was kept open for the shortest possible time.

I designed and installed some very successful furnaces, built on the same general lines, for a large manufacturer of wooden cars, near Buffalo. The grates (under water-tube boilers) were placed a short distance above the floor level, thus obtaining a very high combustion chamber. An ashpit was excavated about 24 in. below the floor level with a trench along the outer face of the boiler fronts through which air entered. This trench was covered with removable plates in front of each of the large lifting charging doors to permit easy cleaning of the ashpits.

The refuse from the woodworking shops was delivered to the boiler room through chutes and consisted of large and small pieces, chips, shavings and sawdust. The fireman piled the refuse in front of the upward-sliding doors, which were balanced in order to operate easily. When the doors were opened the fuel was shoved in quickly upon the large flat grate surface and the doors immediately closed. Two boilers, of about 200 hp. each, were operated in this manner most successfully.

In another woodworking shop in the West, manufacturing furniture, I supervised the installation of another form of wood-burning furnace placed under water-tube boilers.

Here the boilers were set very high above the grate surface and the wood refuse was continuously spouted down tube-like pipes, shooting into the furnace directly through the boiler fronts and landing upon the fuel bed below. A supplementary fire of coal was maintained upon the grates, and thus the plant obtained an ample supply of steam.

I do not know who was the designer of this system, but I protested against its installation on account of danger from fire running back along the wood-conveying spouts. About two years afterwards this plant burned and there was some question raised as to whether or not the cause was due to this system of feeding wood refuse to the furnace.

I have designed and supervised the installation of several different forms of extension furnaces for burning wood refuse, which have given satisfaction. Some of these have their fuel charged through top openings in the covering arch, above the grate bars. The principal defect in this type of furnace is the pyramiding of the fuel on the grates directly below the stoke holes. This can be overcome to a large extent by building up a grate construction under the stoke holes, shaped like a pyramid. This insured a good penetration of air throughout the entire fuel bed and did away largely with the poking necessary to free up the other form of fuel bed.

GRATELESS FURNACE FOR WOOD BURNING

One of the most successful forms of wood-burning furnaces for woodworking shops that I have installed is a grateless furnace similar in its general form to the well-known beehive type of coke oven. It is circular in shape, with a semi-spherical, dome-like cover over the top. I owe my first conception of this type of furnace to my friend, the late F. W. Edwards, of the Standard Oil Company, who was deeply interested in the study of furnace equipments.

25 per cent would mean a saving of 20,000,000 tons in residence-heating work, to which could undoubtedly be added a goodly percentage of coal now used for domestic cooking and hot-water service, by increased economy in its use and by a more extensive substitution of other fuels for cooking.

The practical possible saving on all domestic uses of coal would, therefore, appear to lie somewhere between 20 and 30 million tons. It is important to note that in this 25 per cent saving only 10 per cent is figured as secured from "economy of operation," the remainder being mainly by elimination and lower maintained temperatures.

Having visualized the first two phases of the subject in question, we come to the third phase, viz., the method of procedure that will bring about the greatest conservation. This phase is only indirectly covered by the original subject but is the vital factor which governs the proportion of the possible economies that can be effected.

An active educational program with punch and compulsion in it, as well as an appeal to patriotism, is required, and such a program must necessarily be based upon a plan of regulation and limitation of coal supply calculated upon quantities requiring economy. Only by such means can the average householder be aroused and impressed with the fact that if he does not study and apply the conservation rules, his negligence will react upon the comfort of his own family. He will run short of coal, while his neighbor who has observed the rules will have sufficient for his needs.

Information accumulated leads to the statement that a sufficiently consistent plan of apportioning coal for residence heating, cooking and hot-water service by regulation and limitation, can be secured to make the enforcement practical.

SAVING COAL IN HOT-AIR FURNACES

C. R. Mueller.[1] In a residence of six rooms an estimated saving of 30 per cent of the coal was made last winter without any radical changes in the heating system. The installation consisted of an ordinary hot-air furnace using recirculated air. The means by which this saving was effected may be applied to practically all types of hot-air furnaces, to obtain as good and even better results.

One way of saving coal was to employ the alternate method of firing for the various poor grades of bituminous coal available. Instead of being spread over the whole surface, fresh charges of coal were thrown on one side of the fire only. The red coals left exposed

[1] Detroit, Mich.

on the other side ignited the gases distilled from the green coal, thereby saving the heat which ordinarily would have been wasted up the stack, in the form of unburned gas. Smoking was reduced and the usual explosion, which occurred just after firing, was prevented.

The fuel saving was further increased by lowering the room temperature below that required for comfort in ordinary residences. In residences where the humidity averages 20 per cent or less, during the heating season it is not comfortable unless the room temperature is at least 74 deg. By maintaining a relative humidity of 40 per cent a temperature of 68 deg. was found comfortable. In order to obtain this high humidity it was necessary to substitute for the regular water container pans with twice the evaporating surface, and set them close to the firepot. The pans were kept full by means of a float valve connected to the city water service. Since the amount of water evaporated was comparatively small, the coal consumed in this way was neglected in the following example.

The calculation of the saving which resulted by operating at the lower temperature is based on the fact that the heat loss of a house is directly proportional to the difference in temperature between the inside and outside air. For the city of Detroit the average outdoor temperature during the heating season is 37 deg. The difference between the inside and outside temperatures is 31 deg. for a house at 68 deg., and 37 deg. for one at 74 deg. The saving, then, by the comfortable house with 40 per cent humidity over the comfortable house with 20 per cent humidity is (37 deg. — 31 deg.)/37 deg. or 16 per cent.

In addition to this economy there is, due to the increased humidity, a diminished susceptibility to colds and other pleural ailments.

Recirculating the air in a residence instead of drawing fresh air from outdoors results in a saving of coal, since less heat is expended in warming the inside air through the smaller temperature range. In regard to the healthfulness of recirculation, it can be no more objected to than in the case of steam-heated dwellings, which have no particular fresh-air inlet. Moreover, the air which leaks out of the cracks around the doors and windows is generally sufficient to supply many times more than the amount required for breathing.

The sluggish circulation encountered in the large majority of houses due to the poorly designed air ducts, results in a high stack temperature with its consequent waste of heat. A vigorous flow of air around the firepot and gas passages is necessary to take away this heat and carry it to the rooms above. Good combustion being

maintained, the greatest saving of heat occurs when the stack temperature is reduced to the minimum required for draft. The writer made his largest saving during the past winter by using a 12-in. electric desk fan in the recirculating duct leading to the furnace. The fan was operated about fourteen hours daily, forcing twice as much air through the furnace as would have flowed naturally.

Several tests were made under various conditions, in all of which the superiority of forced circulation was obvious. In two consecutive 24-hr. tests, run to determine the economy of forced circulation, the results in Table 15 were obtained.

Reducing the coal consumption for the conditions of the first test to those of the second based on the ratio of temperature difference, we have $106.5 \times (60/47) = 136$ lb. The coal saving was then

TABLE 15 TESTS OF HOT-AIR FURNACES

Kind of Circulation		Test No. 1	Test No. 2
		Natural	Forced
Duration, hours		24	24[1]
Average temperatures, deg. fahr.	difference, inside and outside	47	60
	stack	309	205
Total lb. coal fired		106.5	78

[1] The fan was run only 17 hr. of the 24 hr. of the test.

$136 - 78 = 58$ lb., which, at ½ cent per lb., amounts to 29 cents. The cost of fan current at about ¼ cent per hour, or 4 cents for the test, makes the net daily saving 25 cents. The saving of coal expressed as a percentage was $100\ (136 - 78)/136 = 42.6$ per cent.

The few published results available on the performances of hot-air furnaces with forced circulation seem to agree to the extent that the efficiency is increased from 5 to 50 per cent by the use of a fan.

The means of saving coal in hot-air furnaces may be summarized thus:

a Alternate method of firing
b Maintenance of a room temperature of 68 deg. with humidity of 40 per cent
c Recirculation of air
d Reduction of stack temperature by forced circulation.

PHILIP J. SAVAGE.[1] Probably the best method of recommending possible economies in residence heating is to summarize briefly some observations and experiences extending over a period of six years and made in connection with the operation of a warm-air generator of well-known make, installed in a ten-room solid-brick residence with average general exposure. Anthracite fuel was used exclusively.

Coal in each of the following forms has been given a full heating season's trial: egg size alone, egg and stove size mixed in equal portions, and stove size alone. Experience indicates that the stove size or smaller coal produces a more compact fire bed, and has the advantage of uniformity of burning rate, causing less loss in the ashes. There was no appreciable loss of unburned coal through the grates with the stove size and, in a furnace of proper size, it produces flexibility and burning speed sufficient for severe weather. Incidentally, the cost per ton is lower for the smaller size.

The proper method of operating the grate shakers or revolvers should be carefully studied and the furnace maker's instructions closely followed. Great economies are possible here, in the lack of waste in the ashes. The variation in practice with identical apparatus is remarkable.

The necessity for a check damper in the smoke pipe, for purposes of economy, is obvious. The smoke pipe and its connection to the chimney should be free of air leaks, as the draft-checking effect may necessitate opening, more or less, the damper in the direct draft, which in most furnaces is designed to cause the hot products of combustion to bypass this damper section and flow through heat-absorbing chambers before admission, indirectly, to the smoke pipe. In the residence referred to, the damper in the direct-draft path is left in the closed position at all times of normal operation, except when the fire is being shaken down and when coal is being added.

The prevention of air leakage at fireplace or grate openings by means of dampers or folding screens, at night and at other times when the ventilating effect is not necessary, is also valuable as a heat saver. Means should be improvised to prevent the all-night loss of heat through the open windows of bedrooms whose doors are left open, for various reasons, to the rest of the house. Stairways can often be more or less completely blocked — by the use of a suitable folding screen, for example. In the residence in question, the morning temperature of the downstairs living rooms has been raised from around

[1] The Detroit Edison Company, Detroit, Mich.

60 deg. to 68 or 70 deg. by means of a screen placed nightly on a stairway, which effectively prevents the convection losses.

Relatively large areas of window and door exposure should be checked up very closely, as heat losses of great magnitude are occasioned by this means. The installation of weather strips on one door, and of storm windows on four large windows with severe exposure, in the residence referred to, effected very marked improvement.

The question of humidity does not seem to receive enough attention. The water pan in most of the hot-air installations, when present at all, is placed in the cold-air intake where the moisture absorption is almost negligible; and in installations of the hot-water or steam systems provision is seldom made for humidifying. At a nominal cost an efficient and automatic humidifying system can be installed in a hot-air furnace, with water pan in the dome above the firepot, where the moisture absorption is naturally greatest. Water pans, with some sort of simple wick arrangement to assist evaporation, placed beside the hot-air registers or over steam or hot-water radiators are appreciably helpful. In the installation under observation, a water pan in the air dome of the hot-air furnace and three pans, each with wick arrangement, placed beside floor registers, have increased the relative humidity during normal winter weather from an average of under 30 per cent to an average of about 45 per cent. An evaporation of over five gallons per day was secured.

By means of the changes above enumerated in equipment and method of operation the coal consumption in the residence referred to has been reduced from an established average of 16 tons per winter of average severity to 12 tons. The expense involved for the double windows, weather strips on a door, a new indoor air feed to the furnace and the humidifying apparatus was $50, and it has been an exceedingly profitable investment, aside from the added comfort obtained.

Robert H. Kuss. The writer has found success when using bituminous coal of the non-coking variety (Illinois or Indiana, prepared sizes) by employing the following methods:

1 Attempt to operate throughout the heating season with the same height of refuse and live-coal level, this being two or three inches above the level of the bottom of the charging-door opening in the usual equipment.

2 Prepare for a new firing by crowding the live coal to the place nearest the firepot-chamber gas outlet. If the gases rise

vertically over the entire firepot area, there is no choice in the matter.

3 Charge the green coal into the depression — which should extend down to the refuse, thus permitting no contact with live fuel except on the surface nearest the placement of the live coal.

4 Regulate adjustments in draft for the period of a day's run by means of the check damper; regulate the maximum and minimum heat delivery (depending upon the severity of the season) by means of the chimney damper. In other words, the check damper is the daily, and the chimney damper the seasonal, draft appliance.

5 Admit very little air over the fire.

6 As the demands for greater or less heat delivery occur, vary the thickness of the refuse from 3 in. for greatest requirements to only a small live-coal area about 6 in. deep for mildest weather.

7 To facilitate refuse removal from the place of greatest accumulation, disconnect the bars of the other grate sections from the shaking lever.

8 Shake grates very moderately.

The results obtained, as compared with usual practice, are as follows:

a Decidedly less combustible in the refuse
b Decidedly less clinkering
c Decidedly less soot formation
d More uniform heat delivery
e Substantial economy increases in mild weather.

ECONOMICAL FIRING OF HOUSE-HEATING BOILERS

DONALD B. PRENTICE. The annual domestic coal consumption of the United States is estimated to be 1.1 tons per capita of total population, and to be 1.4 tons per capita of those living in buildings heated by coal. These figures place the annual consumption for heating, excluding exhaust-steam installations, at 110,000,000 tons, including all grades of coal. If the average efficiency secured in boilers, furnaces and stoves can be raised from 45 to 55 per cent, for example, the same heating results will be produced with 90,000,000 tons. This reduction of 20,000,000 tons would decrease shipments by nearly 500,000 carloads, with an additional saving of fuel on the railroads. Under the present circumstances, of course, these 20,000,000 tons would be shipped as usual and diverted to industries where the need is severe, making an important contribution to relieve the industrial shortage.

Many residences are equipped with hot-water heating plants. A disadvantage of this system is the cooling of the large body of water during the night, and the consequent losses due to forced combustion in the morning, when an effort is made to raise the water temperature rapidly. The greatest cooling effect is felt in bedrooms, especially in children's rooms where windows are often open for twelve hours or more. All hot-water radiator valves when closed permit enough circulation to prevent freezing, which is necessary, but this circulation, unfortunately, is enough to reduce the temperature of the water in the entire system. The writer has found that closing bedroom radiator valves and then carefully wrapping the radiators with blankets will keep the temperature of the water in the system at least 60 deg. higher than it will be if the radiators are exposed to window drafts. If the water is at 140 deg. instead of at 80 deg. in the morning, fuel is saved and the living rooms are more comfortable.

On new installations with sectional boilers it is possible to have two distinct water systems, one for the living-room floor and one for other floors. This arrangement keeps the living-room circuit warm over night. It involves, however, considerably more piping and therefore adds to the cost.

The coefficient of heat loss from glass is four times that for the ordinary residence wall. If shades are drawn completely down after dark at all windows on the first floor and at all windows except those in bedrooms on other floors, and left down until morning, very valuable dead-air spaces are added to the glass areas, reducing the heat loss perhaps 50 per cent. This procedure also checks window leakage to some extent. Although living-room shades are usually drawn, the number of unshaded windows in most houses is surprising. Window shades are important factors in residence heating in another respect — the shutting out of sunlight. Part of the heating requirements of a residence can be met for many hours on sunny days by allowing the interior furnishings to absorb the radiant heat of the sun to the greatest extent possible.

A means of saving fuel in the furnace itself, which is not mentioned as often as it should be, is the use of small sizes of coal. It is quite practicable to burn anthracite as fine as No. 1 buckwheat on the ordinary shaking and dumping grate by carrying the fire on a bed of ashes, provided there is sufficient draft, which is usually true. This small coal, although higher in ash, can deliver as many heat units per pound as the larger sizes for three reasons: (1) For the

same weight the coal has greater surface on which carbon oxidation can take place, which insures complete combustion; (2) the air passes through the fuel bed in fine streams and against enough resistance to keep the excess oxygen in the flue gas at a moderate amount; (3) the fire tends to spread over the whole grate quickly and without manipulation, which eliminates dead spots and prevents air leaks. These statements are not merely expressions of opinion, but conclusions from numerous tests.

L. W. Eggleston.[1] The average rate of combustion in house-heating boilers is about 30 per cent of the rated capacity of the boiler. Most boilers develop their highest efficiency at their rated capacity,

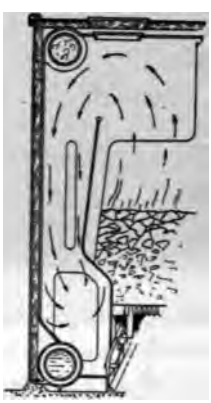


Fig. 17 Principle of Construction of Revertible-Flue House-Heating Boiler

but to secure the most economical results the boiler should have its greatest efficiency at from 40 to 60 per cent of its load. All boilers designed for ascending gas travel are most efficient at high rates of combustion; under low rates of combustion there is not sufficient volume of gases to fill all of the flue space. The gases pass to the chimney by the shortest route without giving up all of their available energy.

The most modern boiler construction is designed with a revertible flue travel, forcing the gases from their natural course. This feature properly applied to a boiler leaves no short cut for the gases to escape to the chimney. The floating effect of the gases while trying to resist the power of the chimney on their downward travel causes

[1] Manager, Sales Engineering Dept., American Radiator Co., Chicago, Ill.

them to press against the heating surfaces of the boiler and give up their available heat under all rates of combustion. This principle of construction is shown in Fig. 17.

Fig. 18 shows two efficiency curves. The lower curve shows the efficiency of a boiler with ascending gas travel. Its highest efficiency is at catalog rating. The upper curve indicates the efficiency of the revertible flue boiler, its greatest efficiency occurring at 50 per cent of catalog rating.

An important step in connection with a steam boiler is to free the system from oil and grease. Oily substances on the surface of the water in the boiler offer resistance to the generation of steam, producing an unsteady water line in the boiler and resulting in a wet-

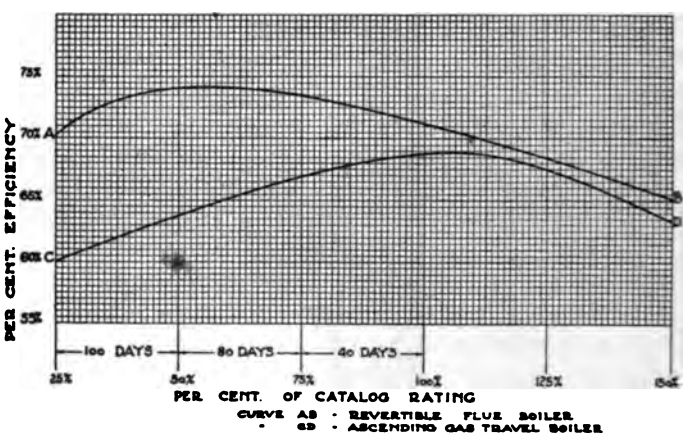


FIG. 18 COMPARATIVE EFFICIENCIES OF REVERTIBLE-FLUE AND ASCENDING-GAS-TRAVEL BOILERS

steam supply to the heating system. It has been frequently demonstrated that a greasy condition in a boiler has increased the fuel consumption more than 25 per cent, and, unless the boiler is thoroughly cleaned after the plant is installed, the grease and oil will remain in the system indefinitely.

The most economical control for house-heating boilers is effected by allowing the greatest possible amount of the draft tension on the boiler at all times. The fire should be regulated by the draft door located in the ashpit. This door should be adjusted so that the maximum results can be obtained with the smallest possible amount of opening. With this control, excess air is prevented and good results are obtained at all rates of combustion. A great many

operators imagine that by closing the choke damper in the smoke hood they prevent the heat from escaping up the chimney. This practice, however, decomposes the fuel without giving off its available heat.

It is very important that the boiler should be made airtight so that the air for combustion enters the draft-inlet door. Thermostatic control, properly connected to the draft dampers, effects a great saving in fuel and gives a more uniform heat.

It has been demonstrated by actual practice that this method of operation, compared with the average manner of operation, will result in a great saving of fuel.

HEAT-LOSSES IN RESIDENCES

P. J. DOUGHERTY.[1] At least 5 tons of coal per year are wasted in the average 10-room residence due to excess air leakage through loose-fitting jambs, windows and doors. Assuming a clearance of $\frac{1}{16}$ in. around the windows and doors, the total area of such openings is equal to that of a 24-in. pipe. Allowing one-half of this area for air infiltration, at least 40,000 cu. ft. of cold air per hour enters the building, while 9000 cu. ft. per hour is ample for a family of five. In zero weather it requires about 5 lb. of extra coal per hour to heat this large amount of excess air.

The heat loss through an 8½-in. brick wall and plaster is 1.8 times as much as through a 13-in. brick wall furred and plastered; or twice as much as through a 17½-in. brick wall furred and plastered. In frame construction the heat loss through a wall consisting of clapboard, studded and plastered, is 1.4 times that through clapboard, paper, studding and plaster; or 1.9 times that through clapboard, paper, sheathing, studding and plaster. It is quite evident that a judicious use of building paper and interlocking metal weather strips will be highly instrumental in reducing coal bills.

The next important leak to be stopped is the excessive escape up the chimney of unconsumed gases such as carbon monoxide, hydrogen, hydrocarbons and carbon. The fuel bed itself acts principally as a gas producer. About one-half of the heat energy of the fuel passes into the combustion space in the form of combustible gases. Unless the combustion conditions within the heater are right, these unconsumed gases carry nearly half the heat value of the coal up the chimney as a dead loss, irrespective of how low the smoke-pipe temperature may be. A high combustion temperature, not less

[1] International Heater Co., Utica, N. Y.

than 1000 deg. fahr., is absolutely essential to produce economic combustion. Invariably a low combustion temperature accompanies a weak draft.

A weak draft, improper firing or faulty heater design are the usual causes of high coal bills because of unfavorable combustion conditions within the heater. The strength of a natural draft depends primarily upon the average temperature of the gases within the chimney, which should range from 300 deg. to 500 deg. fahr., depending upon the height of the chimney. Because of excessive leakage of cold air into the average chimney, and the maximum chilling effect due to the usual 4-in. chimney walls, it is no uncommon condition to have the flue gases chilled from 800 deg. to 200 deg. fahr. in passing from the bottom to the top of the chimney. This condition gives an average stack temperature of 500 deg. fahr., the requirement for the average low outside chimney 35 ft. or less in height. A properly designed heater will therefore permit the gases to escape to the stack at from 400 to 800 deg. fahr. in order to maintain the required temperature in the chimney.

Leaky chimneys are the bane of a heating engineer's existence. A heater cannot deliver heat to the system unless the draft is strong enough to first generate the heat from the fuel. A weak draft changes a heater from a heat producer to a gas producer. The combustible gases escaping up the chimney unburnt are the same gases that are purchased from the gas companies for cooking and lighting. A large saving in fuel and loss by fire could readily be accomplished if the Board of Underwriters as well as city ordinances and architects should demand a smoke test to prove a chimney tight before accepting it, as is the case in testing all plumbing and electrical installations before acceptance.

STRONG DRAFT PROPERLY CONTROLLED THE BEST FUEL ECONOMIZER

A strong draft properly controlled is the best fuel economizer on the market. In the average residence the available draft at the smoke damper should be about 0.2 in. of water. A sensitive draft gage of the Ellison type with a 15-to-1 ratio should be part of the equipment of every heater. No house owner can intelligently regulate the draft without a sensitive draft gage.

A strong draft not only saves coal by producing a high combustion temperature to burn the combustion gases, but it materially increases the effectiveness of the heating surface of the heater. The

heating surface of the combustion chamber will absorb 2½ times as much heat when the combustion temperature is 1350 deg. fahr. as when at 950 deg., the steam or water against the heating surface being at 212 deg. High combustion temperature is far more important than low stack temperature in burning fuel economically. It is far more economical to permit 20 per cent of the fuel energy to pass into the chimney as high stack temperature in order to produce the necessary draft, than to suffer the loss of 40 per cent of the fuel energy in the form of unconsumed gases due to a low stack temperature.

Excess air passing through the heater is a frequent cause of high coal bills. A thin fire on the grates, 12 in. or less, or a strong draft improperly controlled are the principal causes of heat loss through excess air as indicated by a low percentage of CO_2 (from 5 to 10 per cent) in the flue gases.

A deep bed of fire and ash on the grates at all times, from 16 to 20 in., will materially reduce the heat loss due to excess air. Excess air produces such a chilling and deceiving effect that more actual heat units escape from a heater whose flue gases show a temperature of only 300 deg. fahr. and 5 per cent CO_2, than escape from a heater whose flue gases show a temperature of 800 deg. fahr. and 15 per cent CO_2. The former condition represents 19.6 per cent of the heat of the fuel, while the latter with its high stack temperature and low excess air represents only 18.5 per cent of the heat units passing up the stack as sensible heat.

B. J. Denman (written). The greatest saving in districts using bituminous coal for residence heating is to be obtained by encouraging the use of coke. In most residence heaters the volatile matter is distilled off without being consumed, due to the general practice of filling up the furnace in endeavoring to cut down the frequency of firing. This can be avoided by advocating frequent and light firing of coal, or by the use of anthracite coal or coke. The use of thermostats for residence heating is very desirable, and would result in a material saving of fuel in the average house.

C. E. Van Bergen. Fuel may be saved in residence heating by using the smaller sizes of anthracite coal such as pea and No. 1 buckwheat. These can be used by careful handling of grates, taking care at all times to keep some ashes on or over the grates, to prevent the small coal from falling through grates.

Do not shake or dump the grates roughly, and if coal begins to run

through grates, stop it by pushing down enough coal with poker to plug the hole.

WALTER E. BRYAN. Waste in residence heating is due, to a great extent, to ignorance of proper methods of handling heating apparatus. I have found that when it is not necessary to push the fire hard, the most economical results are obtained by keeping the ashpit door and firing door (including the slide) tightly closed and opening the damper in the smoke pipe, which allows air from the outside to enter. The keeping of the fire door tightly closed may result in a little smoking immediately after firing, but it also results in a more even temperature and prevents cold air from being drawn in over the fire.

L. B. MCMILLAN. A great many excellent suggestions have been made regarding savings which can be effected by improved firing methods, heating fewer rooms, and by the employment of lower temperatures balanced to some extent by higher humidity which tends to make conditions more comfortable even if the room temperature is not up to normal. These help to reduce the amount of heat required, while other no less important means make better use of the heat supplied.

It is desirable to keep in the rooms as much of the heat as possible. This of course is affected a great deal by the construction of the building and the insulating value of its walls, etc. Special window stripping of various kinds has been devised to prevent air leakage around windows and doors, and stopping this leakage results in an important saving. The loss of heat through windows can be prevented to a large degree by the use of storm windows.

Frequently the heating pipes, boilers, water heaters, etc., in the basement of a building are either not insulated or only insufficiently insulated. The reason often given is that a certain amount of heat must be supplied to the basement to prevent freezing of water pipes. While this is true, the heat given off from the smoke pipe, in addition to other unpreventable losses, should be sufficient to prevent freezing if the basement is reasonably tight.

10 *What Coal Economies Can Be Effected in the Small Steam Plants?*

E. H. KEARNEY[1]. In order to bring about the best possible efficiency in the plant, the operating engineer should, figuratively

[1] Supt. of Bldgs., John Hancock Mutual Life Ins. Co., Boston, Mass.

speaking, "camp" in the boiler room. Not a single detail of its operating conditions should escape his personal attention — methods of firing, condition of fires, leaks in settings, adjustment of draft, temperature of feedwater and condition of feed pumps are but a few of the many things which should engross his attention. In short, the engineer does well who keeps constantly in mind the truth of the old adage, "If you want a good job done, take pains to do it yourself."

For several years preceding the war period there was a growing tendency upon the part of owners and engineers of medium-sized plants to install apparatus in the boiler room by which a closer check could be had upon fuel consumed, water evaporated, quality and temperature of gases, etc. Larger plants were equipped with these aids to economy as a matter of course, and the beneficial results which attended the operation of these more modern systems had set a worthy example for less pretentious plants to follow.

If increasing scarcity and cost of fuel had been the only factors to be dealt with, it is easily seen that firms dealing in scientific power-plant apparatus would have been swamped with orders. Had prices and delivery remained a fixed quantity, there would have been a scramble on the part of engineers of smaller plants to obtain apparatus which during the 24-hour period would enact the part of watch dogs of the coal pile. But while war conditions brought about a scarcity and soaring price of fuel, they also affected the apparatus manufacturer in like degree, with the result that the modest plant owner found himself between two fires: either to install checking apparatus at a tremendously increased cost, provided he could secure it at all, or to continue under the old order of things by obtaining the best results possible with what he had in hand. Right here is presented a problem for the plant owner who is interested not only in the matter of his own fuel costs, but in the larger scheme of national fuel saving as well.

There is no question but that many plants which are now being operated without adequate provision for bookkeeping and cost checking could make a decided improvement in the appearance of the monthly balance sheet without the expenditure of extravagant sums. It should be the ambition of every power-plant owner and engineer to ascertain beyond reasonable doubt, through the medium of practical expert advice if necessary, whether or not his plant is being operated under conditions which square with good practice.

Reduced to its lowest terms, the whole fuel problem as far as we

engineers are concerned is just this: *Voluntary* fuel saving there *should be;* if not, *compulsory* conservation there *must be.* We as engineers must accept as a duty our share in the great task which now confronts the nation.

D. C. FABER.[1] The possibility of improvement in boiler-room equipment and firing methods in small steam plants was very forcibly impressed upon engineers connected with the fuel-conservation work done in Iowa under the direction of the Fuel Administration last winter. In connection with this work, combustion conditions were investigated in about one thousand small steam plants for the purpose of determining what could be done to improve boiler-room efficiency. While it is not possible to enumerate here the conditions found, there are a number of faults which are common to most plants of this type. In many of these plants the firemen have other duties which take them away from the boiler room for a great part of the time, so that firing instead of being a principal duty becomes merely an incidental one. Under such conditions the firemen usually do about all that is expected of them, which is to shovel enough coal from the pile into the furnace to keep up steam, regardless of how or when this is done, so that carrying too thick a fire, firing too large quantities at one time, and failure to regulate fire with damper in uptake are common faults. Air leaks in boiler settings, bare steam pipes and failure to remove soot and scale at frequent intervals account for a large percentage of the fuel losses in such plants.

Many of these faults can be done away with only through education of owners and operators. Right now, on account of the general interest in fuel economy, is the time to start such educational work. Supervision under direction of the Fuel Administration could well be a part of such educational work. Results can be secured now in the small steam plants which would be impossible under other circumstances.

GEO. H. DIMAN. One of the best ways to save coal is to save the heat units. This can be done in many ways. First, be careful not to have the rooms in the manufacturing plants overheated. Do not allow steam on in rooms with windows open. This summer, see that all the window frames are properly pointed so as to admit no cold air. If operating dyehouses, utilize all the available heat units in the dyehouse and finishing departments.

[1] Consulting Engineer, U. S. Fuel Administration, Des Moines, Iowa.

Let me illustrate what I mean. In one of our large mills, some years ago, the dyeing and finishing departments got behind with their work. In order to get the goods into the market we stopped the mill, running nothing but the dyeing and finishing departments. When the mill was running full we used about 6000 hp. and burned 1000 tons of coal per week. This power was generated by two pairs of cross-compound engines, sacrificing on the vacuum and keeping the discharge water in the condensers at 110 deg. All this water was stored in the finishing department in tanks for washing the goods. A simple engine of 2400 hp. furnished exhaust steam for use in dyeing.

When we ran two weeks with only the dyehouse and finishing room we used direct steam and ran only one engine. It took 275 hp. to turn the shafting of the dyehouse, and we burned 775 tons of coal per week.

It will be seen that in the first case, where the heat units were utilized as far as possible, we got 6000 hp.; while in the other case, where direct steam was used, we got only 275 hp. and burned three-quarters as much coal as before.

B. J. Denman. It is our belief that even in large plants, insufficient attention is paid to intelligent operation of the various boiler and engine units. Efficiency curves of boilers, engines and turbines should be made, and the units operated at their most efficient point. Great savings are possible in many plants if this is done.

One point frequently overlooked is the temperature of the hotwell in condensing units. The amount of circulating water pumped should be varied with the temperature of the circulating water, and the temperature of the hotwell kept as near that corresponding to the vacuum as possible, to reduce the heat loss to the circulating water.

A. G. Christie. This question was discussed informally at one of the meetings of the Baltimore Section last winter. It was pointed out that inefficiency in small plants was generally due to the following causes:

a Practically all horizontal return tubular boilers in the Baltimore district have been set too close to the grates, owing to the fact that a local concern cast boiler fronts from a pattern which allowed only about 20 in. between boiler and grate surface. This has been increased in several cases to 6 ft. with decidedly satisfactory results.

b Air infiltration through cracks in the setting

c Failure to keep the heating surfaces clean

d Improper firing methods

It was pointed out that economies could be secured by:

a Offering a bonus for coal saved

b Keeping careful records of coal used and posting these

c Providing a sufficiently large combustion space over the grates

d Insisting on clean tubes

e Using prepared mixtures to make the setting airtight. Several are on the market. The settings must be inspected periodically to see that they are kept tight

f Elimination of steam leaks through joints, faulty traps, etc.

CARL J. FLETCHER. The question as to coal economies that can be effected in small steam plants in the aggregate is one of the most important questions asked. The fuel cost in these plants is too small to permit the proper expert supervision and the possibility of saving much greater than in the larger plants. After an examination of a great many small plants, I have two suggestions to offer which would result in a very great saving:

Most plants clean the inside of their boilers fairly well; but it is my observation that when soot is removed by hand blowing (done at night when the pressure is low), it is one of the most neglected jobs around the boiler room. Automatic soot blowers should be installed and should be used several times a day.

One other possible saving is in the use of the damper on the individual boilers. Plenty of advice has been given regarding this feature, but I find in most plants that the dampers are inconveniently placed, and often not in real operating condition. As the first step, the plant management should insist that dampers are in good condition, equipped with levers which are within easy reach of the firemen.

P. W. THOMAS. Economies approaching 50 per cent of the requirements in small steam plants of, say, 200 to 500 hp. can often be effected by simply putting the plants in shape. We have a record of one plant using 22 tons daily which now uses 11 tons, and the owners bought no fuel-saving equipment except firebrick, baffle brick, asbestos and fireclay. The 11 tons were saved by the proper education of the men in the boiler room.

WALTER E. BRYAN. Probably the greatest loss in such plants is due to dirty boilers, improper firing and handling of dampers.

If these facts, together with the remedy, could be placed in the hands of the managers of industries who are operating small plants, considerable saving would result.

C. E. VAN BERGEN. As long as the war lasts, no plant using coal for generating steam or for heating purposes can be considered too small to require the careful attention of some one within the organization. Fuel must be saved, no matter how small the quantity, and this is just the point which must be emphasized: "Every plant must save some coal." And along with this is another thought that, unless each one of us saves, we may experience a worse coal shortage next winter. And each of us should preach coal saving on all occasions.

SAVINGS RESULTING FROM INSULATION OF STEAM PIPES

L. B. MCMILLAN. A great deal can be accomplished by improved firing methods, proper air regulation, etc., and men whose experience well qualifies them to advise along such lines have pointed out what steps should be taken to improve the efficiency of combustion.

But it is not enough to get perfect combustion if the heat is lost afterward. Leakage through boiler settings dilutes the gases and cools them off. Any air entering after the coal is burned must be heated to the temperature of the gases and, while some of this heat is given back to the heating surfaces, the air must leave at the temperature of the flue gases and take with it a corresponding excess amount of heat in proportion to the excess amount of air which leaks in. The loss of heat in the flue gases is the largest single loss in the boiler, and therefore anything which increases this still further is certainly bad.

The problem of best economy is not solved even when a satisfactory portion of the heat from the fuel is gotten into the steam. The heat must be kept there until the steam is used and this calls for proper insulation. For each heat unit lost from steam lines at least 1½ or even 2 heat units must be supplied to make up the deficiency. Therefore the saving by insulation is doubly represented at the coal pile.

It used to be common practice, even after the value of insulation became generally recognized, to leave flanges and fittings uninsulated. This is a very wasteful practice as will be seen from the fact that each square foot of surface at the temperature of steam

at 100 lb. pressure loses an amount of heat equivalent to more than one-third of a ton of coal in a year and at 150 lb. pressure the loss is equivalent to nearly half a ton per year. A pair of 10-in. flanges, for example, has an area of about 3 sq. ft.; therefore at 100 lb. pressure a pair of uninsulated 10-in. flanges would waste an amount of heat in a year equivalent to one ton of coal.

Low-pressure steam pipes and surfaces at temperatures around 200 deg. fahr. are frequently left uninsulated on the ground that the temperatures are too low to make insulation on these surfaces a paying proposition. However, even with steam at atmospheric

TABLE 16 HEAT LOSSES FROM UNINSULATED HOT SURFACES

(Air temperature = 70 deg. fahr.)

Steam Pressure, Lb. per Sq. In. Gage	Steam Temp., Deg Fahr.	Temp. Diff., Deg.	B.t.u. Lost per Sq. Ft. per Hour	Lb. of Coal per Sq. Ft. per Year	Sq. Ft. of Surface per Ton of Coal per Year
0	212	142	334	293	6.83
10	240	170	425	372	5.38
25	267	197	522.5	458	4.37
50	298	228	644	564	3.55
75	320	250	737.5	646	3.10
100	338	268	820	718	2.79
150	366	296	960	840	2.38
200	388	318	1079	945	2.12
250	406	336	1184	1036	1.93

NOTE. — This table is figured on the basis of 10,000 B.t.u. available per lb. of coal. The figures for losses in B.t.u. do not depend upon boiler efficiency, but to get at the number of pounds of coal which must be burned to make up the losses, the boiler efficiency and the heat value of the coal must be known or assumed. For example, the 10,000 B.t.u. assumed above is equivalent to an efficiency of about 70 per cent and a coal with heat value of about 14,000 B.t.u. Therefore it is very apparent that the figure is conservative and that in most cases the loss in pounds of coal will be greater than that shown in the table.

pressure only 6 or 7 sq. ft. of surface are required to lose a ton of coal in a year; therefore, it will be seen that in most cases the saving would pay for at least a moderate amount of insulation.

Table 16 shows the heat losses from uninsulated surfaces heated by steam at various pressures. These are given both in heat units and in the equivalent amount of coal. The last column shows the number of square feet of surface at each pressure which are required to lose a ton of coal in a period of one year.

In many cases where insulation is provided the thickness is not sufficient for the results to be accomplished. The so-called standard thickness is not thick enough for any except low-pressure steam con-

ditions, and for every condition there is a certain definite thickness which it pays to put on. It does not pay to use less than this thickness, nor on the other hand does it pay to use much more. Insulation is to be regarded as an investment which pays good returns on the money invested, provided the material is suited to the conditions and the thickness of material is right for the most economical results.

11 *What Experiences Have You Had with the Storage of Coal?*

H. H. STOEK.[1] It is practicable, advisable and advantageous to store bituminous coal not only during war times, but also under normal conditions either at the mines, near the point where it is to be used, or at some intermediate point.[2] It is well to store coal as near the point of consumption as possible to avoid rehandling and for the following reasons:

a To insure the fuel consumer of a supply of coal at all times
b To take advantage of lower freight rates, or of lower prices of the coal at certain seasons of the year
c To permit the railroads to utilize their cars and equipment to the best advantage
d To permit the mines to be operated more steadily.

KINDS AND SIZES OF COAL THAT CAN BE STORED

Although it is undoubtedly true that some coals may be stored with greater safety than others, the danger from spontaneous combustion is due more to improper piling of coal than it is to the kind of coal stored.

Most varieties of bituminous coal can be stored in the air if of proper size and if free from fine coal and dust. The coal must be so handled that dust and small coal are not produced in excessive amounts during the storing, because spontaneous combustion is due mainly to the oxidation of the coal surface.

All varieties of bituminous coal can be stored under water, which excludes the air and prevents spontaneous combustion.

[1] Professor of Mining Engineering, University of Illinois, Urbana, Ill., Chairman of Fuel Conservation Committee, Fuel Administration of Illinois.

[2] The following conclusions were printed in Circular No. 6, Engineering Experiment Station, University of Illinois (The Storage of Coal, by H. H. Stoek), in April 1918. About January 1, 1919, they were submitted to some 200 individuals and firms storing coal during the summer and fall of 1918 and were almost unanimously endorsed as the result of the experience during 1918.

The danger of spontaneous combustion in storing the coal is very greatly reduced if not entirely eliminated by storing only lump coal from which the dust and fine coal have been removed. Of two coals the least friable should be chosen for storage purposes, because less dust and fine coal will be produced in its handling.

Fine coal or slack has sometimes been successfully stored:

a By preventing air currents through the pile by means of a closely sealed wall built around the pile

b By closely packing the fine coal. Such a coal pile must be closely watched for heating.

NOTE: Piles of slack must be very closely watched for heating and means provided for promptly moving the pile if heating develops. The only absolutely safe way to store slack or fine coal is under water

c Many varieties of mine-run coal can not be stored safely because of fine coal and dust mixed with the lumps

d Coal exposed to the air for some time may become "seasoned" and thus may be less liable to spontaneous combustion, due to the oxidation of the surface of the lumps of coal, but opinions are by no means unanimous upon this point

e It is believed by many that damp coal stored on a damp base is peculiarly liable to spontaneous combustion, but the evidence on this point is by no means conclusive. It is safer not to dampen coal as or after it is placed in storage.

EFFECT OF SULPHUR ON SPONTANEOUS COMBUSTION

It has been shown by experimentation that the sulphur contained in coal in the form of pyrites is not the chief source of spontaneous combustion, as was formerly supposed, but the oxidation of the sulphur in the coal may assist in breaking up the lumps of coal and thus increase the amount of fine coal, which is particularly liable to rapid oxidation. Even this latter opinion is not unanimously endorsed. In spite of experimental data showing that sulphur is not the determining element in spontaneous combustion, the opinion is very widespread that, if possible, it is well to choose a coal with low sulphur content for storage purposes.

METHOD OF PILING COAL

To prevent spontaneous combustion, coal should be so piled that air can circulate through it freely and thus carry off the heat due to oxidation of the carbon, or else it should be so closely piled that air cannot enter the pile and oxidize the fine coal.

Stratification or segregation of fine and lump coal should be avoided since an open stratum or a chimney of coarse lumps of coal gives a passage for air to enter and come in contact with fine coal and thus to oxidize it and start combustion.

If space permits, low piles are preferable, as the coal is thus more exposed to the air and better cooled than in high piles, and in case of heating it can be more readily and quickly moved. A disadvantage in high piles is the greater difficulty of moving the coal quickly, if necessary. The idea that a high pile causes heating at the bottom is erroneous, since as many fires take place near the top as near the bottom and near the outside as near the interior of the pile. If possible, the coal pile should be divided by alleyways so as to facilitate rapid loading out of the coal in case of necessity, so that an entire coal pile may not be endangered by a local fire.

Much of the attempted ventilation of coal piles in the United States has been inadequately done by the use of only an occasional ventilation pipe which has been not much more than a place in which to insert a thermometer for reading temperatures. The practice of placing ventilating pipes close together has been used in Canada and is reported to have been effective.

Water is an effective agent in quenching fire in a coal pile if it can be applied in sufficient quantities, but a small amount is ineffective. Unless there is an ample supply of water to thoroughly quench the fire and cool the pile, it is very dangerous to add any water to a coal pile.

Coal of different varieties should not be mixed in storage if this can be helped, for one coal that has a greater susceptibility to spontaneous combustion than the other may jeopardize the safety of other coals that are not so liable to spontaneous combustion.

EFFECT OF STORAGE ON VALUE OF COAL

The heating value of a coal as expressed in B.t.u. is decreased very little by storage, but the opinion is very widespread that storage coal burns less freely when fired in a furnace. Experiments indicate that much of this can be overcome by keeping a thinner bed

on the grate than is kept with fresh coal and by regulating the draft.

The coking properties of most coals seem to be decreased as a result of storage.

The value of certain coals for making illuminating gas is not decreased as a result of storage. Other coals depreciate.

The deterioration of coal stored under water is negligible, and such coal absorbs very little extra moisture. If only part of a coal pile is submerged, the part exposed to the air is still liable to spontaneous combustion.

The best preventive of loss in coal storage is to inspect the pile regularly and if heating occurs up to 140 deg. fahr. to keep very close watch on the pile; and if the heating increases to 175 or 180 deg., to remove the coal as promptly as possible from the spot affected, and thoroughly cool it before piling it again.

Storage appliances and arrangements should be so designed as to make it possible to load out the coal quickly if necessary, and the coal should not be stored in large piles unless provision is made for loading it out quickly.

Pieces of wood, greasy waste, or other easily combustible material mixed in a coal pile may form a starting point for a fire, and every effort should be made to keep such material from the coal as it is being put in storage.

It is very important that coal in storage should be kept from such external sources of heating as steam pipes, because the susceptibility of coal to spontaneous combustion increases rapidly with an increase in temperature.

In piling coal it should be spread in layers over the entire area of the pile and not dropped at one place so that the fine coal will segregate in the center of the pile and the lumps roll to the outside.

T. N. Wynne.[1] The Indianapolis Light and Heat Company has been storing Indiana coal since 1888. Before 1912 all coal stored was on the ground in open air, with no particular attention paid to sizes, quality, or the method of storing. In 1912 this company investigated the question of storing coal under water to prevent spontaneous combustion and loss of heating value. No. 4 vein Indiana coal contains approximately 2 per cent of sulphur and No. 5 vein from 3½ to 6 per cent, and our experience has been that No. 5 will invariably fire if exposed to the air, while No. 4 will not. While we feel it safe to

[1] Indianapolis Light and Heat Co., Indianapolis, Ind.

store No. 4 coal on the ground, it is so difficult to obtain that we feel it necessary to provide storage that will be safe for No. 5. We burn No. 4 on Roney stokers and No. 5 on Green chain grates.

An average of 741 tests shows the freshly mined No. 4 vein coal to contain about 35 per cent of volatile combustible matter. From tests of various samples taken from No. 4 coal stored for three years in open air at our Kentucky Avenue Station the volatile content was found to average 28.34 per cent, indicating a loss of 20 per cent. This coal during its period of storage did not show any signs of heating.

At the same station we have had stored for about eight months 2000 tons of No. 4 vein Indiana mine-run coal. This coal has never shown a tendency to fire, although in places it is 35 ft. deep.

UNDERWATER STORAGE

The history of coal storage by our company has been a series of fires and losses. In 1912 we constructed at our Mill Street Station a concrete pit 300 ft. long, 100 ft. wide and 20 ft. deep, designed to contain 13,000 tons of coal submerged. A standard-gage track crosses this pit at ground level from one end to the other on concrete piers. The cars are run upon this track and dumped. After the coal has reached a certain height it must be handled to both sides of the track by means of a Brown hoist. The topography of the ground prevents the elevation of track to facilitate dumping, a condition very desirable if possible. The pit when filled is not disturbed except in case of shortage in daily delivery. Mine-run coal only is stored because screenings under water become a mud-like mass, almost impossible to handle or burn.

Capillary attraction will take care of coal piled above the water level of the pit as much as 8 or 10 ft., thus permitting of additional capacity of about 40 to 50 per cent.

Whenever coal is taken from the pit to be used on the stokers it is loaded into railroad cars and the water allowed to drain off for about six hours before the coal is put into the bunkers; or, when coal is to be taken from the pit the water may be lowered until sufficient coal has been uncovered and drained to meet the requirements.

The result of underwater storage fully met our expectations in that it prevented fires and preserved the heating value of the coal. We have never been troubled with excessive moisture when burning pit coal if mine run is used. Screenings which have been stored under water burn with difficulty.

A loss of heating value is very evident in the case of coal stored in air. In fact, when burning air-stored coal it is necessary to have additional boiler capacity to carry the same load.

Results of 181 tests of No. 4 vein coal which has been submerged for one year as compared with those of the 741 tests of freshly mined coal previously referred to, show a reduction of 1.7 per cent in available B.t.u. in the case of the submerged coal. This loss is so small that it might very well exist between two lots of freshly mined coal.

Recently we constructed a reinforced-concrete coal pit at our Kentucky Avenue Station, 145 ft. long, 65 ft. wide and 32 ft. deep, built on the same general lines as that at the Mill Street Station and holding 8000 tons.

The Indianapolis Light and Heat Company burns 500 tons of coal per day, and as the two pits have a total capacity of 20,000 tons of coal submerged and 10,000 tons above the water line, this means a sixty days' supply on hand if both pits are filled. The total cost of the two pits was $60,000 or $2 per ton of storage.

DANGER FROM SPONTANEOUS COMBUSTION

ALBERT A. CARY. Another phase of the coal-wasting proposition is that of spontaneous combustion.

With the clean coal formerly received by a certain large power plant, running low in percentage of non-combustible matter, trouble from spontaneous combustion was almost unknown even after the coal had been stored for six or seven years in dense piles.

With the coal now received they find that they cannot store it for two weeks without spontaneous firing; in fact, they have such fires burning in their coal bins almost continuously, with the result that when this supply is drawn upon for use they have coke to burn instead of coal.

With the valuable heat-producing volatile matter thus distilled out of our eastern bituminous coal, the loss in steam-making capacity is from 10 to 15 per cent.

Should coals from the Central West be used (which coals contain a considerably higher percentage of volatile matter), the amount of such loss is materially increased.

Loss from spontaneous combustion simply means that a correspondingly *greater amount of coal* must be carried over our transportation systems from the mines to make up for the deficiency thus created.

The spontaneous combustion of coal is occasioned by the combin-

ation of some of its constituents (including impurities) with atmospheric oxygen, which reactions raise the temperature of the surrounding coal to its ignition point.

Whether this firing is due to the presence of that easily decomposed form of iron pyrites known as marcasite or to the presence of other impurities it is difficult to say, but we have the strongest evidence — at the large power station referred to — that with the clean coal formerly received no loss due to spontaneous combustion occurred, but with the dirty coal that is now being received such firing is almost continuously occurring. Generally speaking, the coals running the highest in non-combustible matter give the greatest trouble due to spontaneous combustion.

P. W. Thomas. Our personal experiences with storage coal may be of great interest. All of our coal is of a nature that heats very quickly. Where we are unable to procure underwater storage, we adopt the following plan:

The storage place is first absolutely cleaned of all rubbish in the way of deadwood and vegetation. We then cover the entire area with coal to the depth of about one foot. After this coal has been exposed to the air for one or two days, we place another layer above it. We continue this to a depth of 8 to 10 ft., being careful to store only coal from one given mine. We have carried raw screenings over a period of a year without smolder, where under ordinary circumstances they would have fired in from one to three weeks. A scientific explanation would be rather difficult, but in all likelihood would center around the undoubted fact that each layer so put down has time to lose the majority of its occluded gases and becomes more or less inert. The pyrite also has time to become partially or wholly oxidized.

Walter E. Bryan. Where coal is not too small in size and contains few impurities, it can be stored either under roof or in the open for long periods with little danger from combustion and, I believe, little deterioration. We have found it necessary in storing screenings, of rather poor quality, under roof, to allow them to stand not longer than three to four weeks in warm weather. In the open it is almost impossible to store such screenings during the summer months without firing, and with the comparatively poor coal supplied last year it was impossible to store the coal for any great length of time, even in the winter months, without its catching on

fire. In my opinion, the question of ventilating storage piles is of doubtful value, the important points being not to store too fine coal or dirty coal, and not to store it in large piles.

In case the coal actually does fire, I know of no effective way to put the fire out; it is our practice to pick up the coal as rapidly as possible and use it. I realize, however, that there are several methods of chemically treating the coal after it has fired which are supposed to put the fire out. In the case of coal stored in buildings, care should be taken after emptying a bin that all pockets are brushed out before the new coal is put in.

B. J. DENMAN. Up to a few years ago I was in charge of plants burning Pennsylvania and West Virginia coking coals which required storage of approximately 100,000 tons. Mine-run coal was stored in continuous piles as high as could be handled by locomotive cranes. No attempt was made to ventilate the piles, and no fires ever occurred. There was no loss in heating value of coal which had been in storage as much as three years.

I am at present storing eastern Kentucky "Elkhorn" gas coal for nine gas plants. Most of this is under cover, but some is unprotected. This coal is stored in piles as high as 25 ft., and no precautions are taken, but no fires have resulted. Most of this coal is ¾-in. lump, but some of it is screenings. Some of the lump coal has been in storage for five years or more.

For electric plants I am at present storing each winter in various localities from 3000 to 20,000 tons of Illinois and Iowa coal. It is our experience that washed central Illinois coal screenings can be put in stock during the summer and used the following winter with very little danger of firing. Springfield, Ill., district 1¼-in. screenings cannot be put in stock in summer without great danger of firing. If this coal is put in stock during the winter time, when the coal is very cold or mixed with snow, it will ordinarily carry through the following summer. Fulton County, Ill., screenings will ordinarily fire before fall if put in stock during the summer months, although we have one plant in northern Iowa where we put about 3000 tons of this coal in stock each year and have very little trouble; in a number of plants in the central part of the state, however, trouble invariably results. This may be due to some climatic condition, but we have not been able to account for it.

We have had very satisfactory results in storing southern Illinois screenings and experience very little trouble. The lump coal from

any of the Illinois districts can be carried through the summer without trouble.

Iowa screenings cannot be stored at all during the summer time, and frequently the coal fires in transit. I have had no experience in storing Iowa lump, but am of the opinion that it would disintegrate and fire.

I have had little faith in the usual schemes for ventilating coal piles, and have observed several experiments which have not been satisfactory. It is our practice not to store the coal over 12 ft. high, and if it begins to heat, to move it as quickly as possible.

A. G. Christie. I have found it impossible to store certain grades of western lignite if wet even in as shallow piles as 6 ft. without having spontaneous combustion. Alberta bituminous coal could be stored in piles 12 ft. deep if kept dry. Wet weather may start combustion. We have had no difficulty storing semi-bituminous coal in piles of 12 ft. deep in Baltimore, but care is taken to keep it dry.

Carl Smerling. It is comparatively safe to store bituminous coal containing up to 1½ per cent sulphur in piles not exceeding a depth of 7 to 8 ft. and not be troubled with spontaneous combustion. The same kind of coal can be stored at any depth if supplied with sufficient air pipes penetrating the storage at proper intervals, although we find that in 50 per cent of the cases where bituminous coal is stored, especially through the Middle West, hundreds of tons of coal are lying in the open for years 20 to 30 ft. in depth and containing from 2 to 2½ per cent sulphur. It must be noted, nevertheless, that in all cases spontaneous-combustion fires are found at the bottom of the pile or at the floor level, and it therefore seems advantageous to have from a foot to eighteen inches of water at the bottom of the pile to insure safety.

C. E. Van Bergen. We do not recall any interesting experiences in connection with coal storage, having never had any large quantities to deal with, nor have we had any fires in storage piles. We do not store until fall, and about 1000 tons well spread in piles not over 15 ft. high is the most we ever have on hand.

W. L. Abbott. We have stored hundreds of thousands of tons of bituminous coal every year at a cost not to exceed 10 cents per ton into and out of storage. We have had no trouble whatever in many years with spontaneous combustion in the coal piles. It has

been our experience that we can prevent spontaneous combustion by storing grades of coal that do not contain the small sizes, using preferably a 3-in. by 6-in. egg or lump size of coal which has gone over a 1½-in. screen.

12(*a*) *To What Extent and Where Will the Gas Producer be Used to Produce Economies?*

ROBERT H. FERNALD. There seem to be three obvious fields for gas-producer development:

1 For extensive power production at the mines
2 As a substitute for natural gas for general heating purposes
3 In conjunction with by-product coke ovens.

1 In the field of power production through the internal-combustion engine the application of the gas producer seems limited to plants of relatively small capacity. This is due to the fact that the practical size limit for gas engines seems to be not over 5000 hp., and very few engines of this size are built. The gas-engine-gas-producer combination can hardly be considered for central-station service. For large power installations the natural development is the by-product producer-gas plant located at the mines in conjunction with steam boilers and steam turbines. The low efficiencies due to the two-step conversion — first, gas generation from the coal, and second, burning of the gas under steam boilers — may be counterbalanced by the development of highly efficient boilers equipped for gas burning, and by the return from the valuable by-products secured from the coal. Should the development of the gas turbine result in commercial units that compare favorably with the present large steam-turbine units, additional marked economies may of course be looked for.

2 The depletion of the supply of natural gas in many regions is leading to the gradual substitution of producer gas in place of natural gas — using producers of either the by-product or non-by-product type.

3 This field embraces two divisions: (*a*) one in which there is an unlimited demand for the coke from the ovens as well as for the gas and by-products; (*b*) one in which there is no market for the coke but a ready market for the gas and by-products.

a This type of plant is composed essentially of two distinct installations, a by-product coke plant and a by-product producer-gas plant. The entire gas output of the coke plant may thus be made

available for the market, as the lower-heat-value producer gas may be used for heating the coke ovens. One of the advantages of this system lies in the fact that coke breeze and low-grade fuels may be used in the producers. In a large European plant of this type the coke-oven gas is the main product and the coke, which finds a ready market, is regarded as one of the by-products. The by-products from the producer-gas plant, sulphate of ammonia and pitch, practically pay the cost of operation of this portion of the installation.

b In case there is a demand for the by-product coke-oven gas but no convenient market for the coke, the natural step involves placing gas producers in close contact with the by-product coke plant, feeding the coke directly into these producers. Such portion of the producer gas as is not used for heating the coke can be mixed with the by-product coke-oven gas for general distribution.

Developments along the three lines indicated seem to offer attractive possibilities, and their adoption on an extensive scale would lead to economy in fuel consumption.

12(*b*) *To What Extent is Natural Gas Being Used as a Fuel for Power Purposes?*

SAMUEL S. WYER. The natural gas industry is in a transition stage, changing from the large-volume, low-price-per-unit basis, to the relatively small-volume and larger-price-per-unit basis. The reasons why natural gas cannot and ought not to have an extensive use for steam-boiler work in the future may be enumerated as follows:

a The number of domestic consumers, now over 2,363,000, is increasing much faster than the number of producing wells

b The initial production and the routine available production coming in are much lower than for wells that came in five years ago. This is due to the general depletion of existing fields, and the extensive underground drainage from past production

c New fields are not being discovered fast enough to replace the rapidly declining present supplies

d The general shortage of coal for domestic heating in the past and the inevitable continuance of this condition for some time in the future, at least during the period of the war, has placed enormous additional demands for domestic heating on the natural-gas resources where natural gas is now and will be used in lieu of solid fuels for heating homes.

Natural gas is preëminently a domestic fuel. Its high heating value, practically twice that of any manufactured gas available, its purity, and ease in handling make it the premier fuel for home use. While low-grade solid fuels can be efficiently used under steam boilers with proper stoking equipment, they cannot be satisfactorily or efficiently used for house heating. For this reason it is a matter of conservation to use the fuel for domestic service that in the long run will yield the greatest good to the greatest number.

The tests recently made in the Home Economics Department of the Ohio State University on cooking various meals with natural gas, soft coal, coal oil, gasoline and electricity, show conclusively that natural gas is by far the cheapest fuel for the domestic consumer's use for cooking. Thus, in cooking a dinner for six people, the total fuel costs, with natural gas at 40 cents per 1000 cu. ft., soft coal at $6.50 per ton, coal oil at 15 cents per gallon, gasoline at 27 cents per gallon, and electricity at 3 cents per kw-hr., were substantially as follows:

Natural gas	0.88 cent	Electricity.....	5.0 cents
Soft coal...	2.5 cents	Coal oil.....	5.4 cents
Gasoline...	4.6 cents		

The rendering of domestic natural-gas service is a public-utility business. Practically all of the states where natural gas is now produced and sold have public-utility commissions with broad powers in matters of rate regulation and quality of service. The general tendency, and the one that is in accordance with sound public policy is to give the domestic consumer first preference and curtail the consumption of natural gas for industrial purposes. For the reasons given in the preceding paragraphs, it may be reasonably expected that this tendency will become more marked in the future and public-utility regulations regarding the use of this best of all of nature's fuels for domestic service will become more exacting and ultimately will result in the very great curtailment of the use of natural gas for steam-boiler work and for other industrial purposes.

12(c) *What Is the Relative Economy of the Locomotive of* 1900 *and Today?*

JOHN E. MUHLFELD. The general development of the steam locomotives in use in the United States since 1900 can be best shown by the data in Table 17, which are approximately correct.

SUMMARY OF ECONOMIC FEATURES

Prior to 1900 considerable development work had been done on two-, three- and four-cylinder types of compound locomotives by Mallet, Webb, Pitkin, Mellin, Vauclain and others. Pitkin's two-cylinder system was applied to a Michigan Central 10-wheel locomotive in 1889, and Vauclain's four-cylinder system was first introduced on a Baltimore and Ohio 8-wheel locomotive — No. 848 — in October of the same year. These and other developments caused the adoption of both the two- and four-cylinder systems in new

TABLE 17 STEAM LOCOMOTIVES IN THE UNITED STATES SINCE 1900

Year	Item	Single-Expansion Cylinder	Two-Cylinder Compound	Four-Cylinder Compound	Mallet Articulated Compound	Total Locomotives
1900	Number	36,600	1,000	900	.....	38,500
	Average tractive power, lb.	19,000	28,000	29,000	.....	.....
	Average wt. on drivers, lb.	85,000	125,000	130,000	.....	.....
1905	Number[1]	48,949	900	1,800	1	51,650
	Average tractive power, lb.	23,000	31,000	32,000	75,000	.....
	Average wt. on drivers, lb.	100,000	140,000	145,000	335,000	.....
1910	Number[2]	56,425	875	1,500	200	59,000
	Average tractive power, lb.	27,000	31,500	40,000	72,000	.....
	Average wt. on drivers, lb.	120,000	142,000	175,000	320,000	.....
1915	Number[3]	62,000	650	1,300	800	64,750
	Average tractive power, lb.	30,500	32,000	33,000	79,000	.....
	Average wt. on drivers, lb.	135,000	145,000	148,000	350,000	.....

[1] Includes 1 superheater locomotive.
[2] Includes 300 superheater and 3000 oil-burning locomotives.
[3] Includes 14,000 superheater and 4250 oil-burning locomotives.

locomotives, the maximum application being reached during 1904, when approximately 1000 two-cylinder and 2000 four-cylinder compound locomotives were in existence.

Previous to 1900 Schmidt, Pielock and others had done considerable experimenting with superheated steam, the former having succeeded in 1894 in producing a boiler and motor in which superheated steam of relatively low pressure was used at about 700 deg. fahr.

The failure of the compound locomotive to produce the economy predicted — due largely to the factors of indifferent design, lack of

proper maintenance and operation, cheap fuel and road failures — resulted in the general return to the single-expansion-cylinder locomotive, and this, with the demand for greater steaming capacity per sq. ft. of boiler heating surface, naturally brought about consideration of the use of superheated steam. The results of further experiments by Vauclain, Vaughan, Horsey, Cole, Emerson, Jacobs and others, along the lines of high and low degrees of superheat, in combination with either high or low steam pressures, by means of smokebox, fire tube, or a combination of both types of superheaters, resulted in the fire-tube type being now practically a standard part of all new equipment, and it is further being rapidly applied to existing saturated-steam locomotives in the United States.

While the Cole and Vauclain balanced-compound types of locomotives as brought out since 1900 — along the lines of the French De Glehn system — have not made much progress, the Mallet articulated compound system, introduced on the Baltimore and Ohio in 1904, is now in use on over fifty railways in the United States, and aggregates more than 1500 locomotives. This latter type of locomotive not only permits extreme concentration of great power over a flexible wheel base within axle-load limits, but also reduces the stresses by greater distribution and lightness of parts, and through the combination of high-pressure superheating, compounding, simpling and reduction of unbalanced pressure gives the maximum direct and reserve tractive power for from 25 to 35 per cent less fuel and water consumption per ton-mile than a superheated single-expansion locomotive.

COMPARISON OF STEAM AND ELECTRIC EQUIPMENT FOR RAILWAYS

With regard to the present status of the relative economy of steam and electric locomotives in the United States, as compared with the results obtained in 1900, general conditions have very substantially changed and the predominating factors today are manual labor and fuel for operation. While the inauguration of the use of fuel oil on almost 4500 steam locomotives has somewhat improved the firing and steam-generation conditions, the increasing cost and demand for oil for more essential purposes and the reducing supply will soon make its use for locomotive fuel prohibitive. However, the use of oil as a locomotive fuel has long since demonstrated that the mechanical feeding and burning of fuel in suspension, whether gaseous, liquid or solid, for the production of steam in a self-contained motive-power unit, is the most logical, successful, effective and econ-

omical method for generating power and moving long-haul heavy-tonnage traffic on railways.

Even where hydroelectric power is available the self-contained steam-power-plant locomotive will show a much lower cost for fixed charge, maintenance and operation than the electric unit, as the transmission and conversion of electric current into drawbar hauling capacity is a very wasteful and expensive process in the present state of the electrical art. In fact, the principal economies brought about in the electrical field during the past quarter-century have been in the production and use of steam for the generation of current and not in the electrical apparatus.

As applied to a long-haul railway, the metering and conveying of extremely high-voltage current from various power-plant sources into transmission mains, through switching substations, transforming and converting, conveying to contact lines and converting into great hauling capacity at the drawbar results in enormous line and bonding dead losses, which will bring the cost of even hydroelectric current per drawbar horsepower-hour to from 6 to 7 mills. This cost, which, in combination with copper limitations, fixed train speeds up and down grades, general tie-up of operation in case of failure, and like factors, will hardly admit of comparison with steam-locomotive boilers operating at equivalent to 700 per cent of the rated capacity of stationary boilers, with a 75 per cent combined furnace, boiler and superheater efficiency, and furnishing a boiler horsepower for each $1\frac{1}{2}$ sq. ft. of evaporating surface and producing a drawbar horsepower-hour for $2\frac{1}{4}$ lb. of coal.

IMPROVEMENTS TO BE EXPECTED IN STEAM LOCOMOTIVES

Nevertheless, the steam locomotive is still in its infancy so far as economy per ton-mile is concerned. The atomization and burning of liquid or solid fuels in suspension will enable the elimination of grates and other metal work from the combustion zone and permit of higher furnace temperatures and more complete and effective combustion, which, in combination with higher steam pressures, compounding, higher superheating of both high- and low-pressure steam, utilization of waste gases and steam for feedwater heating and purification, better boiler-water circulation, reduced cylinder clearances and back pressure, improved steam distribution, lower factor of adhesion, higher percentage of propelling to total weight, less radiation, elimination of unbalanced pressures and weights, application of safety and labor-saving devices, and the greater re-

finement and perfection of general and detailed design, equipment and control throughout, will yet enable it to produce a drawbar horsepower-hour for one pound of coal.

STEAM-ELECTRIC LOCOMOTIVES

Furthermore, it is not inconsistent to now predict that a self-contained steam-electric articulated compound locomotive, combining the advantages of both steam and electric motive power, will shortly find a useful field in services where maximum power and efficiency at high speeds; greater utilization of existing waste heat; high starting and low speed torque and rapid acceleration are required and where an exclusive electrification system would not be permissible from the standpoint of first cost or justified on account of the combined expense for operation and maintenance.

LOCOMOTIVE DEVELOPMENT IN RECENT YEARS

H. B. Oatley. A measure of the real advance made during the past eighteen years in the development of the locomotive is obtainable only when the question is considered in its broadest sense. When viewed in this light, the question may fairly be answered by the statement that the locomotive of today is at least 50 per cent more effective than the locomotive of 1900. The leading factors that produce this result are —

a Adoption of highly superheated steam
b Increase in size of locomotives
c More positive control of mechanical operation and better steam distribution.
d Improved combustion
e Increased average speed over the division
f Increase in the percentage of time available for revenue earning service.

Fuel economies of not less than 20 per cent through the use of highly superheated steam, in all classes of service, have been demonstrated, and over 21,800 locomotives out of a total of approximately 65,000 that are in service on American railroads are using superheated steam. Provisions have been made for the use of highly superheated steam for the standard U. S. Railway Administration engines now under construction. Consumptions as low as 2 lb. of coal per i. hp-hr. have been obtained on engines using highly superheated steam, and in general road operation, under all conditions of weather, a figure of 3 lb. of coal per i. hp-hr. is obtained.

The increase in the size of locomotives during the past decade and a half is strikingly shown by the comparisons of locomotives given in Tables 18 and 19.

The Consolidation of 1900 and of 1918 illustrates the growth in one type of engine, which would not have been possible, economically, had it not been for the successful solution of the problems of superheating, improved steam distribution, mechanical stokers, the use of pulverized fuel, large firebox volume and the increased knowledge

TABLE 18 INCREASE IN SIZE OF PASSENGER LOCOMOTIVE SINCE 1900

Year built	1900	1905?	1918	1918
Type of engine	4-6-0	4-6-2	4-6-2	4-8-2
Road	L. S. & M. S.	B. & O.	U. S. Std.	U. S. Std.
Total weight, lb	171,600	229,500	300,000	350,000
Wt. on drivers, lb	133,000	150,500	180,000	240,000
Cylinders, in	20 × 28	22 × 28	27 × 28	28 × 30
Wheels, in	80	74	79	69
Boiler pressure, lb	210	225	200	200
Tractive power, lb	24,990	35,000	43,800	58,000
Max. i.hp	1,398	1,816	2,624	2,824
Fuel	Bit.	Bit.	Bit.	Bit.
Brick arch	No	No	Yes	Yes
Superheater	No	No	Yes	Yes

TABLE 19 INCREASE IN SIZE OF FREIGHT LOCOMOTIVES SINCE 1900

Year built	1900	1917	1918	1918
Type of engine	2-8-0	2-8-0	2-8-2	2-10-2
Road	I. C. R. R.	D. & H.	U. S. Std.	U. S. Std.
Total weight, lb	216,000	297,000	322,000	390,000
Weight on drivers, lb	196,000	266,000	240,000	300,000
Cylinders	23 × 30	27 × 32	27 × 32	30 × 32
Wheels, in	57	63	63	63
Boiler pressure, lb	210	210	190	190
Tractive power, lb	49,690	66,000	60,000	74,000
Max. i. hp	1853	2,755	2,493	3,082
Fuel	Bit.	Pulverized fuel	Bit.	Bit.
Brick arch	No	Yes	Yes	Yes
Superheater	No	Yes	Yes	Yes

of boiler design which permitted the successful combination of these devices in one engine; and the same conditions are responsible for the growth in the 4-6-2 or Pacific type passenger locomotive, as well as in the 2-8-2 or Mikado type and the 2-10-2 or Santa Fé type engines which have had a rapid development and widespread adoption during the greater part of the period 1900–1918.

The growth in size of the Mallet or articulated locomotive is well illustrated by the comparison between the first 0-6-6-0 engine

built for road service in 1903 and the maximum-sized 2-10-10-2 articulated engine now in service on the Virginian Railway.

The increase in the size of locomotives has been a great factor in cutting down the costs of transportation, by permitting not only large increases in the average weight of trains, but in the incidental advantages accompanying greater train loads, particularly with respect to increasing the capacity of single-track roads.

It is interesting to note that the average tractive power of all engines operating in the United States in 1900 was 17,000 lb. In 1918 it had increased to 36,000 lb. or 126 per cent.

Improved conditions of combustion have been brought about by the study and development of adequate air openings in ashpan and through grates, proper proportioning of combustion chambers, the extended use of water tubes and firebrick arches, greater knowledge as to the proper length and diameters of boiler tubes, and incidentally better design of, and closer attention to, the front-end draft appliances. Full credit should also be given, in this particular, to the efforts on the part of the railroad mechanical officers in the instruction of firemen and engineers in the proper firing and handling of engines. These efforts have shown marked results in eliminating fuel waste from the tanks, at coaling stations and in the handling of the coal on the locomotive. The present interest in feedwater heating is commendable, and advantageous results, when viewed from all angles, have been demonstrated.

Greater average speed over the road has resulted from the building of locomotives of greater power and efficiency, as well as from better knowledge of the proper rating of engines. Overloaded locomotives which are stalled in bad weather or on ruling grades are today exceptional. Twenty years ago they were of very frequent occurrence.

The annual report of the Illinois Central Railroad for 1917 contains a striking illustration of the increase in train loads made possible by the development of the present-day locomotive. In 1908 on this road the average train load per revenue train-mile was slightly under 410 tons. In 1917, it was approximately 700 tons (more than 70 per cent increase in nine years.)

Locomotives of the present day are in revenue-earning work a decidedly greater portion of the time than was the case at the beginning of the present century. Greater efforts on the part of the mechanical organizations to keep locomotives ready for service, have contributed toward this improvement. The progress in design of

locomotive and tender parts subject to wear and the necessity for renewal, have produced, in recent years, details which give far greater mileage between shoppings and thus contribute to increase in hours per day that the locomotive is in service.

These are a few of the principal causes for the conclusion stated in the foregoing paragraphs, that the present-day locomotive may conservatively be stated as not less than 50 per cent more effective than the locomotive of 1900. This very gratifying improvement can be credited, not to any one group of men, but is due to the energy of the railroad mechanical officers, to the locomotive builders and to the engineering organizations which have specialized and developed various devices that are incorporated in the present-day locomotive.

In 1917 the *Railway Review* published a statement made by the General Superintendent of Motive Power of the Pennsylvania Railroad, in which he said: "All of this shows that during the last five years the economy and capacity of our locomotives has been more than doubled, and this has been obtained for an investment in property, in so far as the cost of the locomotives is concerned, that will not amount to a 30 per cent increase." If this is the condition on one road covering a five-year period, it can certainly be accepted as applicable to the railroads of the country over an eighteen-year period.

12(*d*) *What Is the Proportion of Coke Made in By-Product Ovens in the United States?*

C. E. LESHER.[1] The proportion of coke (excluding gas-house coke), made in by-product ovens in the United States has increased from 17.1 per cent in 1910 to 40 per cent in 1917. The figures, by years, are as follows:

Year	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919 (1st Qr.)
Per cent	17.1	22.1	25.3	27.5	32.5	33.8	35.0	40.4	46.2	53.5

The development of the by-product coke industry in the United States up to the close of 1914 was largely the result of the recognition by iron and steel companies of the economies possible by the recovery of by-products and of the flexibility of operation, as well as the assurance of a regular and continual supply of suitable blast-furnace fuel.

[1] U. S. Geological Survey, Washington. Published by permission of the Director.

Beginning in 1915, and most strikingly so today,[1] the necessity for benzol and toluol for explosives and chemical manufacture has given this industry marked impetus. So urgent are the demands for explosives that the Federal Government is expected to finance the erection of additional by-product ovens this year.

These new by-product plants will continue to be operated after the demand for coke — now abnormal — decreases, with the result that the percentage of by-product coke to the total output in the United States will continue steadily to increase.

W. H. BLAUVELT.[2] Preliminary Government estimates place the total coke production for 1917 at 56,600,000 tons, the largest tonnage in the history of the industry. Of this production, 34,000,000 tons, or 60 per cent, was beehive coke, and 22,600,000 tons, or 40 per cent, was by-product coke.

The by-product plants now under construction in the United States will have a capacity of 13,800,000 tons. Not all of these plants now building will be put in operation this year, but the majority of them will, so it seems safe to prophesy that at some time the latter part of this year the production of by-product coke will pass the beehive production. The total capacity of the by-product ovens in the United States now in operation or under construction will be about 41,600,000 tons per annum. This is more than 6,000,000 tons above the maximum production of the beehive industry in 1916, when all of the conditions were favorable to bringing out the greatest possible production from the beehive plants.

12(*e*) *What Are New and Important Developments in Methods of Burning Coal?*

W. W. JOURDIN. Aside from cost, the advantages of fuel oil in steam-boiler practice over rough-crushed coal are so manifest that a particularly strong inducement exists at this time of increasing power costs to apply the economic test to pulverized coal.

The superior thermal efficiency of gaseous fuels is unquestionable, but commercial success in the manufacture of gas for firing under boilers has not been realized. Coal, when ground so fine that 95 per cent will pass 100 mesh, can be conveyed through pipes over considerable distances as readily, almost, as oil, and combustion will occur in a manner quite analogous to that of gas, provided air be

[1] August, 1918.

[2] Consulting Engineer, Semet-Solvay Company, Syracuse, N. Y.

supplied in proper proportion and in intimate contact with the particles of the coal.

That desirable characteristic of oil — easy and complete control of the heating medium to meet variations in steam demand — is inherent in coal in this finely divided state. Better economy is attainable than with coal as commonly fired, since excess air may be kept within narrow limits, and, furthermore, the boiler room is free from heavy storage and handling equipment.

This feature of quick response to variable load conditions cannot be fully appreciated by one whose experience has been confined to stoker equipment. In the plant with which the writer is connected, the excess air is usually maintained within 10 or 12 per cent of theoretical requirements, and with a 50 per cent variation either way from normal load the automatic regulating system will respond so quickly that the extreme variation in steam pressure will be not more than 2 lb. per sq. in., equivalent to 1 per cent of normal. When properly adjusted the damper regulator opens the dampers in time to prevent smoking, in the case of an increase in the rate of firing, or a "clear stack" with a sharp reduction of load.

Steam is the best atomizing agent for oil, but compressed air appears to be most satisfactory for use with powdered coal. All air required for combustion may be compressed by turbo-blowers to a comparatively low pressure, heated by the waste gases, then released in a mixing chamber or burner designed to distribute the charge evenly in the furnace.

The methods used to atomize pulverized coal fall short of requirements since the evaporative efficiency is generally lower, often up to 10 per cent, than obtained with gas or oil. With well-designed apparatus, however, nearly constant oxygen-carbon ratio should obtain over a wide range, and evaporative efficiency need not be less than is developed in the best oil-burning practice.

The grinding and drying equipment should be placed between the boiler plant and coal in storage. The quantity of waste gases to be diverted to the drying plant will depend upon their temperature and the moisture content of the coal. The best performance known to the writer is 4 to 5 lb. of water evaporated per pound of coal used in the dryer; in certain plants the ratio is nearer unity. Therefore, with coals running high in moisture a material saving will be possible by the use of waste gases in the dryer.

A large pulverized-coal plant is being installed in Seattle, where oil is cheap compared to places more remote from the oil fields. If

we cannot afford to burn oil, let us weigh carefully the possibility of utilizing this fine substitute.

12(*f*) *What Economies Have Resulted from Recent Practice in Making Brick Settings Leakless?*

ALBERT A. CARY. The remarkably low flue-gas temperatures frequently reported from boiler tests are generally due to air leakage through boiler settings or at flue connections. A number of boiler tests which I have made were conducted in such a manner as to determine these losses and I will therefore give the results of three or four of these tests from which can be appreciated the gain in efficiency that would result if the air leakage were suppressed.

1 Two horizontal tubular boilers of the same size and located in the same plant, with settings supposed to be identical, gave the following results by taking samples of gas simultaneously from the rear end of the furnace chamber and just inside the flue outlet:

	Boiler *A*	Boiler *B*
Excess of air found in the furnace.....	70 per cent	49 per cent
Excess of air found at the flue outlet.....	103 per cent	71 per cent

These results clearly show how worthless the gas analysis taken at the flue outlet really is as an indication of the conditions of combustion in the furnace.

Turning now to temperature readings taken just inside of the flue outlet, a nitrogen-filled thermometer, with proper corrections applied, showed that the temperatures of gases escaping from the boiler settings were 543 deg. fahr. for Boiler *A* and 482 deg. fahr. for Boiler *B*.

By making corrections for the chilling effect of the infiltrating air we find that had there been no air leakage through the boiler settings, the temperatures of these escaping gases would have been 607 deg. fahr. with Boiler *A* and 562 deg. fahr. with Boiler *B*.

The actual loss in efficiency due to air leakage in these two boilers was as follows: Boiler *A*, 1.73 per cent; Boiler *B*, 2.13 per cent.

The losses occurring in these cases principally were due to the chilling effect of the cold entering air alone, as it was found that practically all of the air leakage occurred beyond the furnace and combustion chambers. A correction of the gas analysis taken at the flue outlet, making allowance for the increased air supply, shows practically the same results as were obtained in the samples of gas taken from the combustion chamber.

2 I will next refer to two interesting tests made with a water-tube boiler having its heating surface widely distributed, and requiring a setting about double the size of a normal setting. It was equipped with stationary grates and hand-fired. One test was conducted at the rated capacity of the boiler, while the second was a forcing test.

During the non-forcing test, I found that the average excess air in the *furnace* was 45.05 per cent, while the excess air found in the escaping gases, just inside of the flue outlet, was 95.79 per cent. There was an unusually high loss in the combined efficiency of the boiler and furnace operation due to air leakage through the masonry; namely, 4.63 per cent.

The average combustion, during this test, was 20.87 lb. of dry coal per sq. ft. of grate.

During a subsequent forcing test, when 40.15 lb. of dry coal was burned per sq. ft. of grate under forced blast, the entire chamber enclosing the boiler was under pressure so that the furnace gases actually blew out through cracks in the masonry and thus we had a case of gas leakage outward.

There is no necessity for employing extraordinary means to obtain tight boiler settings. Long experience has taught me that the material we have been employing for years, if properly selected and properly erected in place, will produce a setting that for all practical purposes is tight and can easily be made to remain tight for years.

It is the duty of every engineer who is called upon to install boiler settings to study the stresses and strains that occur in boiler masonry the same as he is supposed to do in other designing work, and he must also study the widely varying qualities of the various materials used so as to make and secure a proper selection. Extreme expansion and contraction are constantly occurring in nearly every part of a boiler setting and they must be properly provided for. The interior of a furnace wall may be subjected to a temperature of 2000 deg. and running upward to nearly 3000 deg. fahr., while its exterior is sometimes subjected to a freezing temperature.

What can we expect but disintegration, cracking or distortion if provision is not made to meet these conditions. With bridge walls or arches heated to very high temperatures and expanding against the side walls, how can we expect such walls to withstand such pressures without cracking unless provision is made to relieve or prevent such thrusts by proper arrangement of supporting beams, buck stays, pockets in masonry, or other means properly applied?

The average mason knows little or nothing about laying up fire-

brick work and bonding it properly into the red-brick exterior, and yet this most important matter is often left to such men. I always make it a practice to specify exactly how this work should be done.

The market is filled with most undesirable material for boiler setting and if proper refractory material, red brick, mortar, fireclay or high-temperature cement is not distinctly specified, the poor client simply buys his trouble and adds to his maintenance account when he has such unsuitable material dumped into his boiler setting.

Proper provisions must be made for relining furnace interiors without damaging other parts of the setting. Provision must be made for supporting the boiler securely and for taking care of the expansion and contraction of the boiler itself, and the greatest care must be exercised to provide ample foundations which will not settle.

12(*h*) *Is Automatic Air Supply Correctly Proportioned to Coal Supply Possible?*

M. C. M. Hatch. Theoretically, such control of the supply of air necessary for combustion would seem to be desirable. There is a certain amount of excess air which, for a given furnace design, method of firing and nature of fuel, will give the best results, and this excess, expressed as a *percentage*, will be constant throughout the entire range of fuel rates, from lowest to highest.

Accurate control of the air for any method of burning coal on grates, either by hand or by stoker firing, is more or less difficult and may be, and probably is, impossible under many conditions. The comparative sluggishness of furnace action with coal thus fired to respond to rapid variation in load on the boiler and the fact that grates will clinker or ash over, changing the air-inlet area under the fire, account in large measure for the difficulties encountered, and these faults would seem to be inherent in grate firing.

Coal burned in pulverized form offers a chance for development work along the line of positive air control. There is no change of air-inlet area to the furnace caused, automatically, by slagging or ash deposits. The excess air necessary can be readily determined and is materially less, on account of intimate mixture, than in other methods of burning coal, hence, for a given fuel rate, the total amount of air to be controlled is reduced. The flexibility of the furnace, by which is meant its ability to respond almost instantaneously to varying demands upon the boiler, is very pronounced, and this again simplifies the problem.

Pulverized coal, fed by carefully-designed screws which give practically constant delivery per unit revolution for all feeds, affords ideal conditions for standardization work in furnace operation. It is entirely possible, although there has as yet been no attempt made to place such an arrangement on a commercial basis, that the position of the main boiler damper and of the dampers in the induced-air pipes may be synchronized with the feed-screw revolutions in such a way as to insure constant air-excess percentage at all furnace outputs.

12(*l*) *Miscellaneous — School Heating, Insulation, Smoke Prevention*

J. H. Brady chief engineer and superintendent of buildings for the Kansas City School District for the past 32 years, contributed a report made by him to the Board of Directors of the School District of Kansas City, Mo. This report is given in great detail and is extremely valuable. It contains a tabulated statement for 1916–1917, showing the cost per cubic foot for heating the buildings of the school district.

There are 88 public buildings having a total cubic contents of 32,300,000 cu. ft. and an average per building of 367,000 cu. ft. More than half the buildings contain over 250,000 cu. ft. of space and several are much larger. The cost of fuel for all the buildings averaged 3.1 mills per cu. ft. The figures given in the report include the fuel furnished the custodians of the buildings for their residences, except in the case of seven buildings. In what follows is a brief summary of the conclusions:

Grouping the buildings according to the type of heating plant used gives the following results:

Group No. 1, steam hot blast, using fuel oil, average cost 3.5 mills per cu. ft.

Group No. 2, direct radiation, using fuel oil, average cost 3.6 mills per cu. ft.

Group No. 3, steam hot blast, using coal for fuel, average cost 2.8 mills per cu. ft.

Group No. 4, direct radiation, using coal, average cost 2.9 mills per cu. ft.

Group No. 5, frame and brick buildings heated by stoves, average cost 4.1 mills per cu. ft.

Group No. 6, schools heated by hot-air furnaces, using coal, average cost 3.6 mills per cu. ft.

Contrasting two of the buildings, the writer states:

"Central High School shows a cost of 2.7 mills per cu. ft. while Northeast shows a cost of 2.5 mills per cu. ft. The cubic contents of Northeast High is greater than Central High, and the difference in the cost per cu. ft. for heating the two buildings is, in my opinion, due to the fact that Central High has metal frames and sash while Northeast has wooden frames and sash, and the leakage of air or wind around metal sash is greater than with wooden sash. Both these buildings use coal for fuel. As a rule the high cost of heating certain buildings is caused by metal frames and sash, while in other buildings it is due to poor construction, taking into account their age, etc."

Another point is the fact that where mechanical ventilation, or what is known as the hot-blast fan system, using coal for fuel, is installed, the cost for heating per cu. ft., is less on an average than the others, being 2.8 mills.

The fact that the figures for schools equipped with mechanical ventilation run less than for those not so equipped may be attributed to automatic temperature control. The highest cost per cu. ft. is shown where stoves are used for heating, being 4.1 mills.

INSULATION

G. D. Bagley. The insulation of heated surfaces to conserve radiation and convection losses often does not receive the attention which it deserves. Such insulation is necessary regardless of the purpose of the installation or the method of heating. Coverings of the proper thickness and material applied to power plants, chemical plants, heating systems, etc., result in a large saving in coal and a high rate of return on the investment.

The losses from such surfaces range from 2 to 10 B.t.u. per sq. ft. per hour per deg. fahr. temperature difference at the temperatures at which steam is used and amount to 300 tons of coal per year for every 1000 sq. ft. of exposed surface at 100 lb. steam pressure.

The Mellon Institute of Industrial Research of Pittsburgh, Pa., has been engaged for some time in making a study of heat-insulating materials for the Magnesia Association of America, and in order to check up the results of the laboratory work under practical conditions a set of tests was made on a boiler before and after covering with magnesia.[1]

[1] For a more complete account of these tests, see paper No. 1660, p. 667 of this volume.

The tests were made at a mine at Bruceton, Pa., in conjunction with the Bureau of Smoke Regulation of the City of Pittsburgh. The two boilers used in the tests were of the locomotive type, 60 and 80 hp., fire tubes and single pass. They were installed on concrete piers without coverings. The total uncovered surface was 675 sq. ft. and the average pressure 80 lb. per sq. in.

Each test covered a period of 24 hours. The firing was under the supervision of the Bureau of Smoke Regulation in order to have it as consistent and regular as possible. The coking method was used, firing the coal in the front of the furnace, leaving the fire door open for a short time after each firing, and breaking the coal back as it coked. This method of procedure resulted in nearly smokeless combustion of the fuel.

During the first test, 10,784 lb. of coal were used and 58,000 lb. of water were evaporated. This corresponds to a rate of 6.35 lb. of water from and at 212 deg. fahr. per lb. of coal as fired.

After the first test was completed, the boiler was covered with 1½ in. of magnesia blocks and plastered with magnesia cement and a coat of hard-finish cement for protection, making a total thickness of about 2 in. The boiler test was then repeated, taking great care to hold the load at the same values as during the first test, and to keep all other conditions the same.

In the second test, 59,500 lb. of water were evaporated and 9296 lb. of coal consumed, giving a rate of 7.55 lb. of water from and at 212 deg. fahr. per lb. of coal as fired and a saving of 1488 lb. of coal per day.

If calculated for an equal water evaporation, the saving would be 1700 lb. of coal. It seemed much easier to hold a nearly uniform pressure after the boilers were covered and this probably accounts for the excess of the measured saving over that calculated, as the coal was burned more uniformly and the boiler efficiency was higher.

The saving in coal as shown by this test amounted to about 15 per cent of the coal originally burned. The per cent saving will vary with the amount of exposed surfaces in proportion to the capacity of the boilers. The losses shown by the test are those due to heat loss from the boiler alone and do not take into account the losses from the pipe lines which cause condensation and wet steam in addition to wasting coal.

The tests show that the losses from uninsulated surfaces are large enough to amount to a very considerable factor in the total coal consumption of the country, and to warrant every one who is inter-

ested in the conservation of fuel in seeing that all surfaces, however small, are properly insulated.

SMOKE PREVENTION

VICTOR J. AZBE. In regard to smoke prevention, if we would base our studies upon furnace volume, gas velocity, composition of volatile matter, and take into consideration eddies and whirls, dead space, etc., we soon would have information enough collected to design furnaces for any type boiler and any fuel so smoke would not be produced. That most furnaces are built upon unscientific principles can be shown by a study of gas flow with a fairly accurate anemometer in a cold boiler when the damper is open.

No. 1650

SOME ECONOMIC ASPECTS OF FIRE-PROTECTION PROBLEMS AND HAZARDS IN WAR TIMES

By J. Donald Pryor[1] and Frank V. Sackett,[1] Providence, R. I.
Non-Members

This paper seeks to point out the hazards involved at the present time in the war work of five great essential classes of industry, namely:

1 *Metal Workers*
2 *Textile Mills*
3 *Shipyards*
4 *Flour Mills and Grain Elevators*
5 *Piers, Wharves and Docks.*

The engineering problems in connection with the adequate protection of such properties have to a large extent been solved but the necessary safeguards are lacking, due either to a failure to grasp the necessity for such safeguards or to economic conditions.

Standard automatic-sprinkler protection is the most dependable means of safeguarding these various classes of risks, but in shipyards and piers that protection alone is not enough, but must be reinforced by hydrant systems, certain structural changes and the organization and careful training of private fire brigades.

IN its essentials the fire-protection problem in war times does not differ from the fire-protection problem in peace times. It is true that war conditions aggravate and increase ordinary fire dangers, but the means found most efficacious for combating them in normal times are still most efficacious.

2 A great deal has appeared in the daily press on incendiary fires set by German agents, and the colossal amount of our fire losses last year — totaling as it did some $250,000,000, an increase of more than 25 per cent over normal — encouraged the belief that enemy aliens were responsible for the greater part of our staggering contribution to the fire Moloch.

[1] General Fire Extinguisher Company.

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers.

3 Unquestionably, enemy agents did cause heavy fire losses — perhaps $30,000,000, but according to the National Board of Fire Underwriters certainly not more than this. If only about 10 per cent of our fire losses since we have been in the war have been due to enemy aliens, surely our attention should be focused on some means of stopping the remaining 90 per cent of the losses in quite as great a degree as it is on checking enemy spies.

4 Last year's increase in the fire loss is readily accounted for when we realize the tremendous speeding up of industry, the employment of unskilled labor, night-and-day operation and crowded storage, all of which have been part and parcel of our participation in the world conflict. Compared to other countries these considerations are those which have always made the fire losses of America the most amazing piece of wastefulness the world has ever seen.

5 In no country in the world has fire-protection engineering in the way of appliances for fighting fire, either manually or automatically, reached so high a degree of perfection as here. Nowhere in the world has fire-resistive construction been developed to such an extent as here. But in spite of this our fire losses, even in peace times, are staggering. In part this is due to our tremendous values. In some measure it is due to our large-area buildings and high-speed production, and in great measure it is due to our carelessness.

6 But at the present time our values are mounting higher and higher. Production is being speeded as never before. Surely the answer to our problem cannot be found by correcting either of these elements in the situation, for we positively must increase supplies and further speed up production. There remains for us only one way in which to effect the cure for this red disease which is sucking our re sources, and that is to be more careful that fires do not start and more careful that we have at hand the means for putting them out when they do start, as some of them inevitably will.

7 The usual business building, be it manufacturing plant, storage warehouse, dock, pier or shipyard, is roughly classified by the insurance companies as being protected or not protected. It is a curious commentary that at present the three most essential classes of property in our country are those least protected. They are in order of their importance as follows:

a Shipbuilding yards
b Flour mills and grain elevators
c Piers, wharves, docks and storage warehouses.

There are two other great classes of vital industry — metal-working establishments, including foundries and machine shops, and textile mills, in which we have placed cotton mills, full-process knitting mills and woolen mills.

8 The average munition works, being a metal-working risk, has not the severe hazard of the foregoing classes of risk, and yet the fire loss among the metal workers is in itself astounding, and that industry, while its largest units fall into the protected class, has many small units where values have not to date been sufficient to induce owners to fully protect such property. Our textile mills producing clothes for our soldiers are the best and most completely protected class of property in this country, and probably in the world.

FIRE PROTECTION OF METAL-WORKING ESTABLISHMENTS AND TEXTILE MILLS

9 Before passing to a consideration of the fire-protection problem of the three unprotected classes of essential properties noted in Par. 7, it may be well to outline briefly the fire-protection equipment of the two protected classes of property, namely, metal-working establishments and textile mills, and see what new demands the war has made on their fire-fighting facilities.

10 The increased hazard of fire in metal-working establishments has to do almost entirely with processes incident to their manufacturing ammunition, and a complete outline of the processes involved is almost essential to the thorough understanding of the new hazards involved. Except for one or two increased hazards in the treatment of steel, most of the new processes where serious hazards are involved are those having to do with the loading of the shells rather than with the making of the various parts. This whole matter is treated in detail in a paper by W. D. Milne, Inspector of the Underwriters Bureau of New England, in the Proceedings of the National Fire Protection Association for 1917.

11 Perhaps the quickest way to illustrate the comparative safety of most large metal-working plants from ordinary fire danger is to briefly review an investigation made a year ago in this class of property. That investigation showed that the average insurance rate paid by metal-working concerns, unprotected by automatic sprinklers, was $1.47 per $100, and that the average rate paid by these same concerns after having installed automatic sprinklers was 20 cents per $100, a reduction of 86 per cent in their average rate.

12 It should be remembered, however, that the requirements made by the insurance companies for sprinkler protection, which is the main dependence of all of these concerns, include certain other protection devices such as chemical extinguishers, oftentimes hose and hose connections and the installation in some cases of fire doors, the closing up of vertical openings and, in many cases, the installation either of open sprinklers or fire shutters to guard the plants from exposure fires.

13 Since the insurance rate is invariably the truest measure of fire danger, it is readily apparent that these metal-working plants which have automatic sprinklers and other auxiliary protection are about as safe from the ordinary fire as it is humanly possible to make them.

14 The only danger from ordinary fires in these protected plants is that the fire-fighting equipment, either through carelessness or maliciousness, may become impaired, and in 1917 there were several disastrous fires in completely protected properties due to water's being shut off the sprinkler system.

15 The same type of protection that is enjoyed by these metal workers has been carried to its ultimate development in the great textile mills of the country, which were the pioneers in installing automatic sprinklers, and which are today enjoying rates on the average of from 7 to 10 cents per $100. They, just as the large metal-working establishments, are immune from ordinary fire dangers provided their fire-fighting equipments are kept in working condition.

KEEPING SPRINKLER SYSTEMS EFFICIENT

16 Unfortunately the fire-fighting equipments of these risks are not always in operative condition, and naturally the cleverly directed incendiary would take care to see that the sprinkler equipment was shut off, or otherwise put out of order before applying the torch. This danger of enemy activities and also the fact that more unskilled labor than ever before is being employed in both these classes of industry, makes it particularly worth while to consider in addition to sentries and watchmen some automatic means of safeguarding their fire-fighting equipment, which equipment, in the last analysis, is automatic sprinklers.

17 The sprinkler-fire tables of the National Fire Protection Association show that out of 19,000 sprinkler fires in all classes of risk there have been 851 specified by the insurance companies as unsatis-

factory. Of these 851, over 25 per cent, or 230, occurred because the water was shut off the sprinkler system.

18 As far as keeping the sprinkler service in all classes of risk in operative condition is concerned, and particularly as regards keeping the service intact in these special classes of risk, the most absolute safeguard is what is known as sprinkler supervisory service. This service is installed and maintained by the American District Telegraph Company and, briefly, consists of having the vital elements in a sprinkler system equipped with electric alarm apparatus, which automatically transmits a code signal to the central office whenever anything out of the way happens to the sprinkler system, in addition to automatically transmitting an alarm to the control station in case of fire.

19 For instance, as regards the matter of water being shut off the system, there would be a switch placed on all controlling valves of the system, and if any of these valves, either through malicious intent or carelessness, were closed, the A. D. T. office would at once receive a signal of such closing and would immediately send a runner to correct the difficulty, or at least to ascertain if the owners were aware of the fact that their fire protection was impaired. The same general type of device can be applied to other elements of the system, but the mere equipment of controlling valves by protecting apparatus is one of the essential precautions which war conditions impose upon manufacturers who have otherwise adequately safeguarded themselves against having their production stopped and thus seriously interfering with the country's war work.

20 Where supervisory service is not available, or for financial reasons will not be considered, the importance of this matter as evinced by the figures above quoted warrants the stationing of a man at any controlling valve of a sprinkler system which is closed for any reason whatever, and the keeping of that man there until the valve can be again opened and the system restored to service. Theoretically, if this stationing of men were religiously carried out this problem of closed valves and consequent heavy losses in protected properties could be avoided; but, unfortunately, the human element is such that this plan can never be considered as the ultimate answer to the problem.

21 The other chief causes of so-called sprinkler failures are generally defective equipment or water supplies and unsprinklered sections, these causes contributing 279, or 32 per cent, of the 851 so-called sprinkler failures in all classes of risk. For the most part defective

equipments are those installed in the very early days of the sprinkler business, before the present standards of appliances and installation were reached, and engineers should take care to thoroughly investigate the equipment in plants in which they are interested to see that it is in every way up to standard.

22 The matter of unsprinklered sections has always been a bothersome one and it is particularly so in metal-working risks, because to the layman there are a great many sections of such plants where it seems almost impossible for a fire to start and gain headway. But it should be remembered that no man can tell when and where a fire will start, and that as far as the ordinary sprinkler equipment is concerned, an unsprinklered section acts to all intents and purposes as a severe exposure hazard; and in this time, when metal production is so necessary, every safeguard should be taken to see that such production is not stopped.

23 While it is true that the larger metal-working establishments, including automobile factories, are completely safeguarded by automatic sprinklers, it still remains a fact that there are a host of smaller establishments in this industry which are not so protected. The products of these smaller factories are often used in the larger, and patriotism demands that they should be protected against fire. Just remember that since 1908 nearly sixty million dollars in unprotected metal-working risks have been destroyed by fire, and the necessity of further protecting the smaller units of this industry becomes obvious.

THE SHIPBUILDING INDUSTRY

24 In general, there are two great classes of shipyards: (*a*) shipyards like the Bethlehem plant at Squantum, where the building ways and the slips are completely enclosed, and (*b*) the smaller yards where the ways are built in pairs with a runway between, and where there is seldom a roof over the ways, and practically never enclosing side walls. In the first type of yard the fire-protection problem is in most respects similar to the equipment of any large metal-working establishment or combination wood- and metal-working risk.

25 The more common type of shipyard, especially on the Pacific Coast and on inland waters in the eastern part of the United States, consists of office, storehouse, carpenter shops, etc., and, where steel ships are being constructed, machine shops. These buildings are immediately above the ways and are usually of light wooden construction, generally one story high with a peaked roof, and sometimes

a concealed space. The driveways and yards leading down to the shipyards are often planked.

26 The shipways themselves are close to the water's edge and are arranged in pairs, each pair being separated by wooden platforms or piers. These platforms on the land side are nearly the ship's depth lower than the completed hull and a wooden stairway leads to an overhead platform or runway between each pair of ways. The timbering of the ways sometimes supports a light roof to protect the workmen, but the sides are practically never enclosed.

27 Obviously, this type of yard is a very serious fire risk, for almost invariably there is a strong wind blowing on the water and a fire starting at one end of the yard might well wipe out the whole enterprise in short order. Obviously, also, no scheme of protection can be devised which will invariably and infallibly protect such a plant, as it is impossible to expect automatic sprinklers to protect adequately the open-sided roofs of the ways where there is a roof, and sprinklers cannot be installed advantageously in the timbered runways.

28 The plan which has met with the greatest favor in safeguarding shipyards of this type is to run a large water main the whole length of the yard between the shipways and the buildings. The buildings are then completely sprinklered and feed mains are run from the large main down each platform, between each pair of ways, and hydrants are installed with an ample supply of hose so that fire on a burning way or ship can be fought from both sides. Usually two hydrants on the platform are considered sufficient. An improvement on this plan would be to install a standpipe with hose connection, which could be operated from the overhead platform above the lower working pier. This would provide vantage ground for fighting fires in the holds of ships partially completed without the delay of dragging a hose line up the stairway.

29 In shipyards where wooden ships are being constructed and where consequently there is an enormous amount of lumber stored, the risk approximates that of the ordinary lumber yard. Such lumber yards should, of course, have adequate protection in the shape either of a complete hydrant system or, better still, a system of standpipe monitor nozzles. The monitor nozzle is supported by a concrete pole having a platform at the top where is located a switchbox for starting the automatic pump. These nozzles have been used in a considerable number of car-storage yards and have given splendid satisfaction.

30 Briefly, this system consists of a series of standpipes about 24 ft. high, each carrying a monitor nozzle and a platform at the top. The standpipes are spaced about 90 ft. apart, and such spacing allows the nozzles to absolutely command any fire in the protected area. A ladder leads from the ground to the platform so that one man can quickly get the nozzle into operation and by reason of a set screw direct it on the fire and then proceed to set another nozzle into operation, thus effectually attacking the blaze from several standpoints.

31 The initial water supply to this system can as a rule be taken from the mains which feed either the sprinkler system or the shipway hydrant system, but in addition to this there should be a fire pump taking suction either from city water, a reservoir or any other large supply such as a pond or river. The pump is controlled by a switch on the platform of the standpipe so that after the primary supply has been started there may be no delay in providing the extra pressure which such sweeping outdoor fires require.

32 At the base of each standpipe there is a post indicator valve which the operator opens before he goes to the platform. In connection with this valve there is also a drain which should always be left open when the nozzle is not in use, so that there may be no water left in the standpipe. This insures against freezing, which is one of the serious faults of the usual hydrant system.

33 The thought naturally occurs that the yards building wooden ships would be much more hazardous than the yards building steel ships. But this is not always the case, because the constant dropping of red-hot rivets in steel ship construction on the wooden platforms causes many fires and the underwriters feel that the danger is practically equal to the danger in the yards building wooden ships.

34 Obviously, the various types of system above outlined for protecting the ways are largely dependent upon human activity, and the importance of the shipbuilding program would seem to warrant the yards in having specially trained men to handle their fire-fighting apparatus.

35 The fire brigades organized in a great many of the factories insured under the mutual system or with the Factory Insurance Association are extremely efficient and no better plan could be followed by the shipyards than to adopt these same measures, because a lot of untrained men with a long length of writhing hose will succeed in making themselves ridiculous about as often as they will succeed in making the fire so.

FLOUR MILLS AND GRAIN ELEVATORS

36 Next in importance to the active prosecution of our shipbuilding program is the production and conservation of foodstuffs, particularly wheat. France and England are now on short wheat rations and we ourselves have had to curtail our consumption seriously. But in spite of this tremendously grave situation, the National Board of Fire Underwriters declares that we burn up wheat in grain elevators and flour mills at the rate of about $10,000,000 annually, the total destruction of foodstuffs running to about $25,000,000 a year.

37 That this rate of burning can be very greatly cut down by adequate protective measures, the chief of which is automatic-sprinkler protection, is clearly evinced by a study of the sprinkler-fire records and by a comparison of the fire-insurance rates on such properties before and after protection.

38 The records of the National Fire Protection Association, covering 70 fires in flour and cereal mills protected by automatic sprinklers, show that in 54.3 per cent of the cases the fires were completely extinguished by the sprinklers and that in 37.2 per cent of the cases the fires were successfully held in check. Of the so-called unsatisfactory fires making in all 8.5 per cent of the total, half were due to partial sprinkler installation or exposure fires, leaving only 3 fires out of the 70 where the type of construction was such as to handicap proper sprinkler performance, or where the hazard was too severe for the ordinary sprinkler system.

39 The same records show for grain elevators a total of 52 fires, 38.5 per cent of which were completely extinguished by the sprinklers and 32.7 per cent successfully held in check. Out of the remaining so-called unsatisfactory fires there were only 6 where the hazard of occupancy or the nature of the building was such as to make unsatisfactory the performance of automatic sprinklers.

40 This record shows why the average insurance rate on flour mills and grain elevators before the installation of automatic sprinklers and other protective devices is $3.03 per $100 and why after such protection it is $1.01 — a 66⅔ per cent reduction. There is no doubt but that the hazards involved in this class of property are many and severe, not only as applied to the processes carried on but on account of the general nature of the construction.

41 One of the greatest hazards in flour-mill operation is in the fast-running machines and in the processes of cleaning and reducing the grain. Nails and bits of wire are often drawn into the separator

and cause sparks, resulting frequently in dust explosions. In this connection a report made many years ago is of interest. On May 2, 1878, the Washburn Flour Mills, Minneapolis, were wrecked by an explosion. A commission investigated and tested flour and coal dust. It was concluded that "all finely divided carbonaceous material will explode."

42 The great number of elevators and conveyors running respectively vertically and horizontally through the plant make an enormous addition to the fire risk. The chances for fire to get a good start and to spread rapidly are so great that automatic sprinklers are placed somewhat differently from the method used in the ordinary factory building. The heads below the ceiling are spaced according to the usual standard, though frequently a little closer together. Around the elevators they are spaced as closely as they can be put without interfering with each other. They are also placed as near as possible to the elevator legs. The latter act in case of fire as veritable flues. To offset this an automatic-sprinkler head is placed at the top of the elevator head inside the hood. The entire volume of water from this head would be discharged down the elevator leg and deluge any fire within it.

43 Freight and passenger elevators and stairways make another great hazard, and sprinklers are placed close to the elevator wells and under all stairways. Sprinklers are also placed at the top of the elevator shaft to protect the machinery, while the great number of nooks, crannies and other out-of-the-way places in such a building all have to be adequately protected.

44 The protection of the storage bins in the elevator section of the plant is a problem in itself. In cases where the bins are subdivided at the various floors, the same ceiling arrangement of sprinklers is adopted as in the mill building itself. In some installations, particularly where the storage is arranged in the form of silos, additional heads are placed beneath the floors of the silos, as well as in the space between the walls and the sides of the silos.

45 A considerable percentage of unsatisfactory sprinkler fires in this class of risk were made unsatisfactory by vertical openings or faulty construction. The maximum sprinkler efficiency cannot be expected where the automatic sprinklers are at a disadvantage with regard to distribution of water or rapid spread of fire, such as is produced by vertical openings, flimsy construction or concealed spaces sheathed in wood. All of these elements tend to spread a fire rapidly and should be avoided in every case possible.

46 In spite of the fact that sprinkler protection obviously minimizes the danger of fire in flour mills and in spite of the fact that insurance rates are so largely reduced for such installation, there are, comparatively speaking, but few of this class of risk under protection. The very large mills almost invariably have such protection, as do the elevators in connection with them. But up to the present time economic considerations have prevented carrying this protection into smaller mills, country elevators and terminal elevators on the wholesale basis that the hazard and irreplaceable values at stake demand.

47 A great number of these smaller mills are located in sections where there is no adequate city water supply and the consequent expense of tanks in connection with the equipment has worked to keep these properties unprotected; for business men seem invariably to demand that as far as fire protection is concerned they must be shown a very large and attractive investment through insurance savings or else they will not install the equipment.

48 In the country grain elevators the same condition applies as regards water supplies and in addition the grain stored in the elevators is in many cases not owned by the same parties who own the elevator. Moreover, it is usually stored for a period of only three to five months. This combination of circumstances and the seeming inability of the owners of the grain and the owners of the elevator to get together on a coöperative basis has worked to create a financial barrier against the equipment of these properties with automatic sprinklers.

49 As regards the great terminal elevators, the question is not one of water supplies as these are in most cases available. Even where they are not, the values at stake are so great that the savings by reason of sprinkler equipment would pay for the systems in a comparatively short time. The trouble here is an exaggerated case of the same thing that exists in the country elevators, namely, that the elevator owners and operators do not own all the grain being stored or in process. Since the great value at stake is in the grain itself, and since owners of the grain cannot see why they should spend their money to improve an elevator which they do not own, enormous quantities of irreplaceable food values are at the mercy of fire in one of the most hazardous classes of risk.

50 While the engineering problems involved are a little more difficult than ordinary, they have been satisfactorily solved and the protection of these properties is held up for financial reasons rather than on account of engineering considerations.

SEAPORT PROBLEMS

51 One needs but to visit any great Atlantic seaport today to see almost unbelievable quantities of supplies congested in piers, wharves and storage warehouses for shipment abroad. Our seaports are literally packed with vital necessities for France. No better idea of the fire hazards incident to such seaport congestion can be given than to quote from a book written by Fire Chief John Kenlon of New York, who perhaps has had more experience in fighting water-

FIG. 1 GENERAL VIEW OF COMMONWEALTH PIER, BOSTON, MASS., SHOWING MISCELLANEOUS FREIGHT. NOTE PARTICULARLY THE BALES OF COTTON

front fires than any other man in America. Here is what he says of fire-protection problems in American seaports:

The sheds or wharves, common to America, form about the most dangerous structures of their kind in existence. Built on wooden piles, with wooden superstructures, they are comparable to nothing but horizontal flues, through which flames rush with a lightning rapidity, rendering abortive any efforts on the part of the fire department unless the greatest promptitude is shown by all concerned, and demanding the use of fireboats with specially designed and extraordinarily powerful equipment. Fill these sheds with every sort of combustible material imaginable: hogsheads of resin, bales of cotton, crated furniture, barrels of pitch, stacks of dry goods, and such unconsidered trifles as a few boxes of celluloid toys

and novelties, and can the mind of man conceive a collection of heterogeneous merchandise more calculated to provide the wherewithal for a conflagration and matter enough to assuage the thirsty pens of all the newspaper reporters in the town? Yet this represents an every-day condition in an American port, and it is perforce necessary not only to guard this property but to calculate the even more important risk, namely, should fire occur, the danger of its spreading to adjacent dwellings.

FIRE PROTECTION OF PIERS

52 The protection of pier properties involves special hazards which require special attention and constant following up and on account of the extreme importance of this matter, we outline briefly, in detail, the conditions found on piers.

53 *Construction.* Construction varies to a considerable extent, but the tendency of the past few years has been to improve the type of buildings used for this purpose. In general, piers consist of one-story corrugated-iron buildings supported on wooden frames and wooden piles. Sometimes they are two-story buildings, but always with high ceilings and large openings in the sides for loading purposes. Almost invariably they connect by unprotected openings with adjoining bulkhead buildings of ordinary construction and considerable size.

54 *Area.* One of the worst features of piers is their large area, which is all open and subject to heavy drafts. Very seldom are these areas broken up by dividing walls, and unquestionably some good could be accomplished along these lines. While some objection might be made to this arrangement on the ground that it would interfere with operations on the pier, it should be noted that piers with dividing walls are being satisfactorily operated.

55 *Accessibility.* From the very nature of piers, they are less accessible than ordinary buildings. Their location near railroad terminals or on waterfronts means a frequent delay on account of congested traffic conditions. Furthermore, the ordinary building is accessible to firefighters from all four sides, while piers are accessible only from one side, and that is always the shortside. Approach from the water sides may be cut off by barges blocking the slips, and regulations should be made to keep these slips clear so that fire boats can approach from all sides.

56 *Occupancy.* The handling and storage of all sorts of supplies, from dangerous chemicals to aëroplanes, which must be received in whatever condition they are delivered by the transportation companies, is a dangerous operation. Furthermore, there is a constant

change in the kind of material passing through from day to day, and this changing in itself produces a hazard, as elements that may be safe enough in themselves are frequently brought in contact with other elements which may cause them to be dangerous. Undoubtedly one of the worst features about this miscellaneous stock is the trouble with broken packages and containers, and the constant spilling of the various contents about the pier, where they may cause trouble later on.

57 *Hazards.* The lighting and heating hazards are about the same as in the ordinary building and apparently well taken care of, but of course they must be continually followed up.

58 SMOKING. No matter what regulations there are regarding smoking, it is a hard matter to handle. The danger from this source is always present and the only remedy is to keep after the matter and treat offenders severely.

59 HELP. The scarcity of labor has resulted in the employment of undesirable and irresponsible help. It is a case of that or nothing, and certainly results in an increased hazard in handling. These men are not efficient, and are not trained in matters of fire protection as well as in ordinary times. There is no remedy for this condition except a careful and continual watching of these men.

60 EXPOSURES. Piers are subject to exposure fires not only from adjoining frame structures on land and other piers but also from vessels along side and floating material from other fires in the vicinity. They are much more susceptible to exposure fires than ordinary property because the high winds prevailing on the waterfront carry flying brands greater distances and fan these incipient fires wherever they start. An excellent illustration of this feature was the Jarvis fire on the Jersey City waterfront, which spread across the river to a pier in New York. The vessels alongside and in the harbor are also hazards because the employees on board are careless about fire-protection matters and are not under restraint by the pier owners. Frequently boats containing dangerous contents catch on fire and they may expose several piers in the same harbor.

61 *Fire Protection.* Too much emphasis cannot be placed upon the necessity and importance of ample water supply for fighting pier fires, and yet during this last winter a large section of the Jersey City waterfront was greatly endangered by low pressure in the city mains. Reliable reports indicate that at the time of the coal shortage and very cold weather the city pressure at many points near pier property was *under 10 lb.*

62 This danger was somewhat offset by good private supplies, but it simply indicates how bad things can get when not properly followed up. The size, location and condition of all mains and outside fire hydrants are matters that must have continual attention, or they are liable to fail during an emergency. Instances of this kind have already occurred.

63 INSIDE STANDPIPE AND HOSE. For instant use with incipient fires and to hold them until the fire department arrives, proper standpipe and hose connections are essential and are generally provided. It appears, however, that this form of protection is open to some objections not common in other property, namely:

a Subject to freezing, as shown by many cases that happened last winter

b Liable to be used by crews of boats alongside for purposes other than fire and damaged or left out of condition by them

c Frequently inaccessible or blocked by piling of goods too near hose racks

d Control valves are necessarily located out of reach, and when the operator finds the fire too severe he is liable to run without stopping to close the valve, allowing the waste of water when most needed

e Condition of piping where salt water is used frequently requires special attention on account of barnacles, pitting, etc. The only remedy for these conditions is constant inspection and frequent tests of the apparatus.

64 EXTINGUISHER PAILS AND CASKS. The value of this form of protection lies in the fact that every one knows how to use pails and casks, and if used in time they may save loss. They must be looked after frequently to see that they are ready for instant use.

65 WATCHMEN. The importance of having strong, alert young men is becoming more apparent. When it is remembered that every night the entire protection of great value is solely dependent upon their good judgment and faithful efforts in a monotonous job, it will be understood that first-class men must be employed. It is also advisable to have a watchmen's checking system and they must be thoroughly instructed in detection and fighting of fire.

66 FIRE ALARMS. Both city and local fire alarms are desirable. The important thing is to give the alarm promptly upon the discovery of the fire as assistance cannot be rendered too soon. For some reason

or other there seems to be more trouble with delayed alarms in connection with pier fires than with other classes of property, and too much importance cannot be laid upon the necessity of early alarms for pier fires. Local fire gongs operated from the same box are desirable for the purpose of notifying all employees immediately, and furnish the best method of drilling them.

67 FIRE BRIGADE. A well-trained fire brigade is a very great advantage because these men are constantly on hand and available. Their jobs depend upon getting the fire out. Further, on account of their familiarity with the property and the fire-fighting apparatus, they are able to get at the trouble very quickly. Surprise tests should be made by the owners frequently to see whether they are properly responding to alarms.

68 AUTOMATIC SPRINKLERS. The value of these systems is well known and where properly maintained there is no question as to their efficiency. Pier conditions require special consideration, as follows:

a They must be dry systems because the piers are not heated

b High ceilings and particularly draft conditions make necessary curtain boards to bank the heat at sprinkler heads for high efficiency

c Extra heavy water supplies are required because of the large area subject to one fire

d Outside sprinklers are sometimes necessary to protect from exposure fires on vessels, etc., that may be alongside of the pier

e Sprinkler supervisory service for the purpose of automatically calling in the fire department whenever a fire starts

f Proper housing for mains and dry valves to prevent freezing during cold weather.

69 Considering the serious hazards in pier property, it is a surprising fact that only a comparatively few piers have been protected with automatic sprinklers. For example, out of some 150 piers in Manhattan we find only one or two with standard sprinkler equipments. Brooklyn makes a better showing with 18 sprinkler equipments and New Jersey with about a half dozen. In the entire country there are only about sixty piers safeguarded with sprinklers.

70 We find that it is practically the unanimous opinion of all the fire-protection engineers that sprinkler systems afford the best possible protection for this class of property, and many of them believe it to be the only satisfactory form for their particular conditions.

71 Mr. E. P. Boone, of the New York Fire Insurance Exchange, has had more experience with sprinklered piers than any one else in the country, and he is an enthusiastic believer in sprinkler systems for piers. His experience covers a number of actual fires which have resulted in only nominal loss to the property on account of the quick action of the sprinklers. Figs. 2 and 3 give a good idea of the way Mr. Boone adapts sprinkler protection to the special conditions existing on a pier. Large open areas are broken into sections by special curtain boards coming down from the ceiling which bank the heat at the sprinkler head in spite of the drafty conditions. Note that some curtain boards are parallel with the pier, and others intersect them at right angles, running across the pier together, forming large pockets for the heat to rise in. This construction is rather unusual and is made necessary on account of the extreme width of the pier. Fig. 2 also indicates the great length of the pier. These views show one of a group of sprinklered piers owned by the Bush Terminal Company, whose property was recently taken over by the Government. Fig. 4 shows the sprinkler layout for a typical pier property, and Fig. 5 a section through pier indicating provision for a metal fire curtain.

72 Everybody's business is nobody's business; and we firmly believe that serious trouble will result unless the entire matter is handled in a businesslike manner by some high authority with broad experience in this line. We submit:

a That there should be no question as to the reliability of all water supplies involved, either public or private

b That lighters and boats exposing piers should be compelled to conform to established fire-protection practice and not be permitted to endanger this property by using kerosene lamps, cooking stoves, etc.

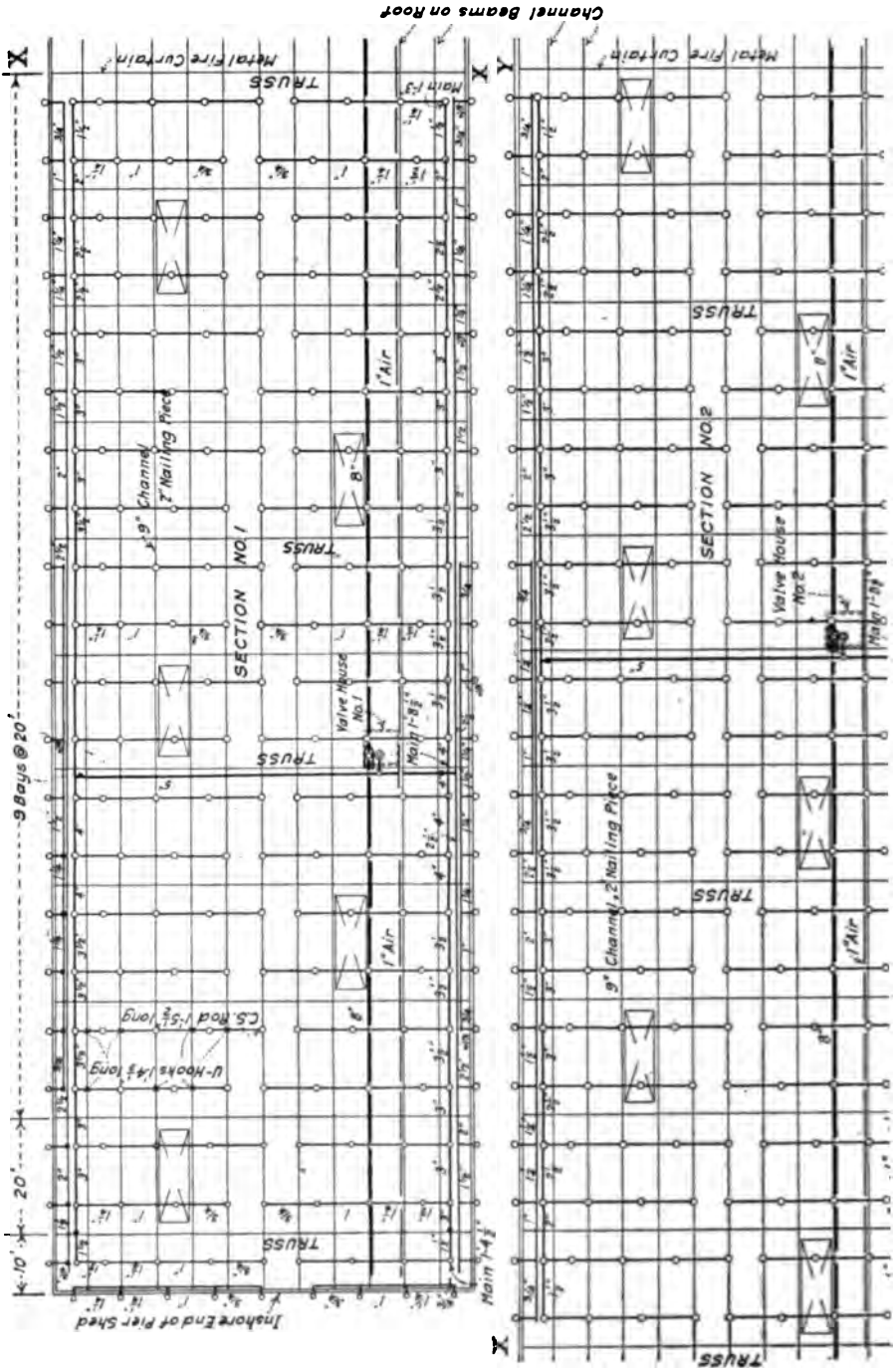
c That dangerous chemicals, oils and highly inflammable materials should be segregated and kept separate from other supplies

d That barges and boats should not be permitted to block up slips, preventing access to the sides of piers

That extra large areas should be divided by section walls or fire breaks

FIG. 2 SPRINKLERED PIER IN BROOKLYN, N. Y. NOTE CURTAIN BOARDS INSTALLED TO BREAK UP CEILING AREA AND BANK HEAT AT SPRINKLER HEADS

FIG. 3 ANOTHER VIEW OF PIER SHOWN IN FIG. 2. NOTE PARTICULARLY THE CURTAIN BOARDS RUNNING LENGTHWISE OF THE STRUCTURE


Channel Beams on Roof
Metal Fire Curtain
Metal Fire Curtain
X
X
Y
X
TRUSS
TRUSS
TRUSS
TRUSS
TRUSS
TRUSS
Main 1-4½"
Main 1-3"
1" Air
1" Air
1" Air
1" Air
8"
8"
8"
8"
9" Channel
2" Nailing Piece
9" Channel, 2" Nailing Piece
SECTION NO. 1
SECTION NO. 2
Valve House No. 1
Valve House No. 2
Main 1-8½"
Main 1-8½"
C.S. Rod 1-5½" long
U-Hooks 1/4" long
9 Bays @ 20'
10'
20'
Inshore End of Pier Shed

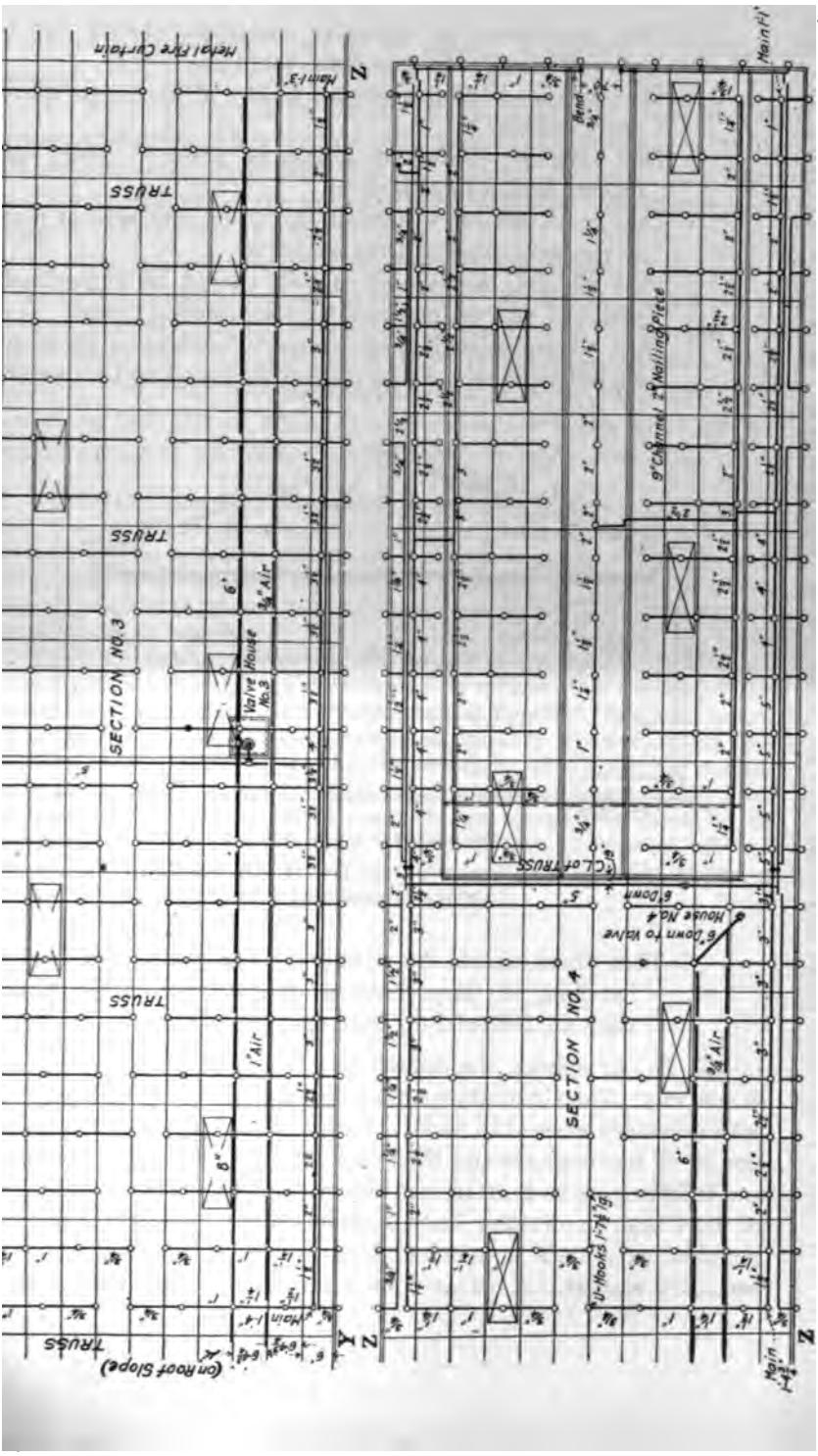


FIG. 4 SPRINKLER LAYOUT FOR A TYPICAL PIER [illegible] THE OPEN SPRINKLER EQUIPMENT TO [illegible] GUARD AGA[illegible]

f That explosives, or explosive materials, should not be permitted near the important terminals

g That bulkhead buildings should be cut off from piers wherever possible

h That sprinkler protection should be provided where conditions appear most serious

i That good, reliable watchmen should be employed at night to properly safeguard the contents

j That all dirt, waste and rubbish should be immediately removed and the premises kept scrupulously clean

k That, wherever lacking, all necessary fire-fighting apparatus should be provided and constantly tested and inspected

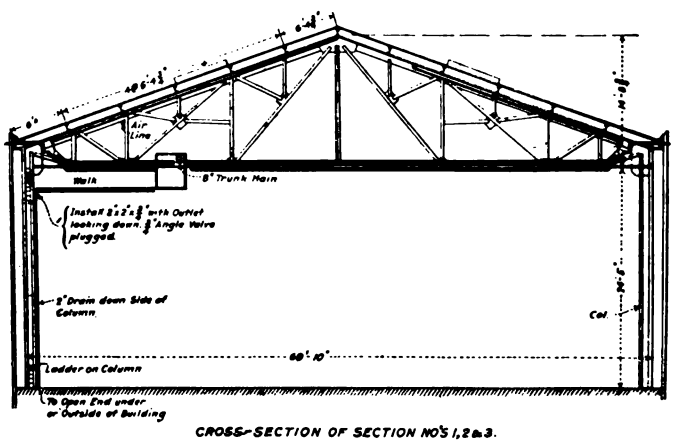


FIG. 5 SECTION THROUGH PIER OF FIG. 4 SHOWING PROVISION FOR METAL FIRE CURTAIN

l That there should be a uniform practice established for handling all these matters and particularly seeing that they are followed up from day to day.

73 In our opinion the desired results can be accomplished only in one way: The Government must create a special central authority with necessary experts to make a complete study of the entire situation in all our seaports and then place the responsibility of handling and following up such matters in this one central authority. It must be more than an advisory body, and should be composed of men with practical experience in such matters, and capable of enforcing the necessary regulations. This step is not only justified as a matter

of business expediency, but is in reality a matter of military necessity.

74 We have sought in the foregoing to outline some of the broader principles of fire protection in essential industries, but in the last analysis each individual risk has its own particular problems which must be solved for the individual plant by the engineers in charge.

75 One thing that applies to all plants, all offices and all houses is the matter of cleanliness and carefulness. What this country needs is more careful national housekeeping and in this connection the writer asked the Fire and Accident Prevention Committee of the National Fire Protection Association for a brief outline of the work it is doing this year in trying to reduce the fire losses which are so serious a drain on our national resources. In reply they said:

> We plan to incorporate where possible, ordinances giving the fire department power to enter premises for clean-up purposes and to correct various undesirable features. We are at present formulating a program to include the education of school pupils in the details of fire prevention in the home, and to bring to the public a realization of personal responsibility for fires originating on their premises, whether homes or business.
>
> We are also arranging for parades and demonstrations and suitable literature through committees which are to be formed in various cities throughout the country. As to your paper before the Mechanical Engineers, that is an opportunity for you to place before them the great necessity for incorporating fire-protection features in their plans when they are called upon to outline any project. We must rely upon the engineers of the country to help us in the broader field, and where plants are being erected usually the first consideration should be the preservation of that property from fire. Their realization of this need will be a great help, not only in reducing the fire waste of the country but in preserving the necessary output of materials in this time of war.

No. 1651

REPORT OF THE COMMITTEE ON WEIGHTS AND MEASURES ON THE METRIC SYSTEM IN EXPORT TRADE

To the Council of the American Society of Mechanical Engineers:

In its study of the extent of use of the metric system, your committee secured copies of a report entitled, "The Metric System in Export Trade," made by Mr. F. A. Halsey to the American Institute of Weights and Measures, an organization having for its main objects the maintenance and improvement of the English system of weights and measures.

This report is based upon more than fourteen hundred answers to a questionnaire which was sent to several thousand manufacturing concerns in the United States, some or all of whose product is shipped to countries which are supposed to use the metric system.

It is the only instance which we have been able to find where an earnest and sincere effort has been made to get at the actual facts with respect to the use of the metric system in export trade from the United States. While a great deal has appeared in print on this subject, nearly all of it was based on conjecture or limited knowledge. This report, as stated, gives the actual facts reported by more than fourteen hundred manufacturers.

The information contained is of such great interest and value to all who are studying this question with a desire to get at the truth, that we feel that our Society would be rendering a real service if the essential facts of this report as deduced from the replies to the questionnaire were presented to the membership. Your committee, therefore, offers herewith a comprehensive abstract of this report which comprises a careful summary of the replies received and the conclusions to be drawn from them.

Respectfully submitted,

L. D. Burlingame, *Chairman* — J. Sellers Bancroft
E. M. Herr — A. L. De Leeuw
F. A. Halsey — *Committee on Weights and Measures*

Presented at the Spring Meeting, Worcester, Mass., June 1918, of The American Society of Mechanical Engineers. For discussion, see The Journal, July 1918, p. 530.

IN view of the thoroughness of the inquiry, this report may fairly be regarded as a census of the use of the metric system in this country.

The inquiry took the form of a questionnaire, which was sent to the following lists of manufacturers:

1 The members of the American Institute of Weights and Measures, many of whom are exporters

2 The members of the American Manufacturers Export Association

3 Those included in a card list of exporting manufacturers compiled by the American Manufacturers Export Association

The total number of those to whom questionnaires were sent exceeded 6000. No selections were made from these lists, the questionnaires being sent to every name upon them. The number of countable replies received was 1445.

Form Letter No. 1

——————1917.

American Institute of Weights and Measures,
20 Vesey Street, New York.

Gentlemen:

Referring to your inquiry regarding our experience with weights and measures in foreign trade, you will find that experience summarized below:

We have been engaged in foreign trade for ..... years.

Our line of products consists of .....

In our factory work, and in order to adapt our goods to the needs of buyers in metric countries, we have found it desirable to abandon English measures and use, instead, metric measures for the various dimensions of our products to the following extent:

Not at all		Make a cross in the appropriate square.
Slightly		
Considerably		
Extensively		
Exclusively		

Exclusively is understood to mean the absence of all English dimensions in the product — not a few metric dimensions in every shipment.

Remarks and Particulars

We have found it advisable to pack our goods for trade with metric countries in containers of metric dimensions or containing metric weights to the following extent:

Not at all		Make a cross in the appropriate square.
Slightly		
Considerably		
Extensively		
Exclusively		

Remarks and Particulars

In our literature for and correspondence with metric countries, we have found it advisable to give information regarding weights, output, capacities, over all dimensions, etc., in metric terms as follows:

Not at all	
Slightly	
Considerably	
Extensively	
Exclusively	

Make a cross in the appropriate square.

Remarks and Particulars

Yours very truly,
The Questionnaire

THE FIRST QUESTION

In our factory work, and in order to adapt our goods to the needs of buyers in metric countries, we have found it desirable to abandon English measures and use, instead, metric measures for the various dimensions of our products to the following extent:

This question is by far the most important of the three. When a manufacturer makes his products to the millimeter to the exclusion of the inch, he has, in truth, adopted the metric system and until he does that, he has not adopted it. The giving of catalog information in metric terms is a use of the metric system, but a use exactly comparable with the use of the Spanish language in catalogs for Spanish America and is no more the adoption of the metric system than the printing of such catalogs is the adoption of the Spanish language.

In 19 cases returned questionnaires included different lines of products in the production of some of which the metric system is used and in others not. In some of these cases the fact was noted in the questionnaires, and in others it was brought out by another form letter. These 19 cases have been added to the summary of industries below, but not to the tabulated summary of the answers.

Replies to the first question are summarized in Table 1.

TABLE 1 SUMMARY OF REPLIES TO THE FIRST QUESTION

	Count of returns	Per cent
Not at all	1189	82.3
Slightly	160	11.2
Considerably	29	2.0
Extensively	16	1.1
Exclusively	5	0.3
No reply to this question	46	3.1
Total	1445	100.00

NO USE OF THE METRIC SYSTEM IN PRODUCTION

The following extracts from letters make a suitable introduction to this phase of the subject.

The Addressograph Company (addressing machines, in export trade 12 years) write:

Only one request for goods to be marked in the metric system in the past 12 years.

The American Printing Company (textiles) write:

We have equipped some of our cloth-folding machines to record meters instead of yards so that we can meet requirements for lengths in meters, but practically all our goods for export are measured in yards.

The American Rolling Mill Company (iron plates, sheets and billets, in export trade 7 years) write:

In many Latin markets, the English measurement system has been adopted for our line of goods by the majority of buyers.

The American Stove Company (stoves; in export trade "many" years) write:

As to factory methods of measurement, we have made no change whatever in order to adapt our goods for export. All of our goods are made to English standards of measurement.

The Babcock Printing Press Manufacturing Company (printing machinery; in export trade 30 years) write:

We consider the proposition of changing our system of weights and measures to the metric system as no more necessary or desirable than teaching the men in our shop the language of the country in which the machine is to be run.

The Berger Manufacturing Company (sheet metal products; in export trade for 15 years) write:

We find that customers [in metric countries] are invariably acquainted with our system and that they are able to make conversions into our weights and measures the same as we do when an inquiry comes to us in metric.

The Black-Clawson Company (paper mill machinery; in export trade 25 years) write:

We have had no trouble whatever using English measures.

The Boston Pressed Metal Company (metal stampings; in export trade 10 years) write:

France, Russia, Argentine, Brazil, Denmark, Australia and Canada use regular stock of inch sizes.

The Bristol Patent Leather Company (in export trade 12 years) write:

The largest leather producing countries use the square foot as their basis, therefore, the square foot is a familiar unit even in countries using the metric system.

F. W. Brody & Co. (cottonseed products), in export trade "many" years), who reply Not at All to all of our questions, add —

And our exports the past season were approximately $1,000,000.

The Brown Folding Machine Company (paper-folding machinery, in export trade 20 years) write:

We cannot recall any instance where we have been asked to give anything but United States standard weights and measures.

The Brown Portable Conveying Machinery Co. (portable conveying machinery; in export trade 6 years) write:

The foreign buyer buys from our standard sizes nearest to his approximate metric requirements.

The Cleveland Automatic Machine Company (machine tools) write:

We rarely have occasion to make up specifications using the metric system for abroad. We ship a vast amount of material to foreign countries.

The Collins Company (cutting tools; in export trade 70 years) write:

Our business is nine-tenths with foreign countries. We have no need whatever to use the metric system in our business.

The Cudahy Packing Company (packing-house products; in export trade for 30 years) write:

We do an export business amounting to many million dollars per annum, but have not found it necessary to mark our goods with anything but the usual English weights.

The Cadillac Automobile Company write:

We have been shipping automobiles abroad for 15 years and have never had the question of metric measurements raised by any of our correspondents or customers abroad.

Curtis and Marble Machine Company (cloth-finishing machinery; in export trade 40 years) write:

Where the goods are measured by the roll or drum system, we use the regular yard circumference drum and then use compensating gears to reduce this to meters. In the South American trade there are four or five different lengths used, none of them metric and each a specific measurement for individual countries.

The Benjamin Eastwood Company (textile machinery) write:

There is no call for the metric system of weights and measures in building textile machinery for export. We have had many inquiries and cannot remem-

ber a single instance where the inquiry has specified that the machinery must be built under the metric system.

The Chase Turbine Manufacturing Company (woodworking machinery; in export trade 40 years) write:

One customer has a scale attached to the machine to indicate width of opening. This scale is graduated according to the metric system.

The William J. Dines, Jr., Company (plantation machinery; in export trade 6 years) write:

When we receive orders for machinery, it is usual to receive a sketch showing the proposed installation and the dimensions are more often given in feet and inches than in the metric measures even from countries using the metric system.

The Dodge Steel Pulley Corporation (steel pulleys; in export trade 17 years) write:

All made in English dimensions.

Eastman, Gardiner & Company (building lumber; in export trade 12 years) write:

After the meeting of the National Foreign Trade Council last year during which meeting the matter of the metric system for foreign business was brought up, we took the matter up with our foreign agents in France, Belgium, Germany, Italy and England and asked them if there would be any advantage in our adopting the metric system in figuring lumber. They stated that although the metric system was used in some of the above countries that in lumber, the buyers were so accustomed to using the English measure that it would be a great mistake to make any change in our method of figuring.

Fairbanks, Morse & Company write:

We have been actively engaged in developing foreign trade for the past 15 years and our experien e touches practically every country in the world. The lines of goods that we manufacture and sell abroad are quite varied, embracing internal-combustion engines, steam, power, and centrifugal pumps, electrical dynamos and motors, railway supplies and windmills.

We are, of course, sending our goods to countries where the metric system is used, but we have not seen any necessity whatever for abandoning the English standard of weights and measures.

The Fawcus Machine Company (gears and gear drives; in export trade 16 years) write:

On one occasion we made some special machinery to drawings furnished by a customer in Spain on which metric dimensions were used. We readily transcribed them into English.

The Glasgow Iron Company (steel and iron plates, etc.) write:

Orders for our product come to us in feet and inches, and are so marked when shipped.

The R. P. Hazzard Company (men's shoes; in export trade 10 years) write:

We have never had called to our attention any metric system for designating sizes of boots and shoes.

The Hess Machine Works (file-making machinery; in export trade 25 years) write:

We have exported to all parts of the world where files are manufactured and we have never departed from the American standard.

The Independent Pneumatic Tool Company (portable pneumatic tools; in export trade 24 years) write:

We have never used the metric system nor have we been asked to do so.

The Lauderdale Cotton Mills (colored cotton goods; in export trade 4 years and who place their cross in the Not at All line) write:

Our entire output is being exported.

Libby, McNeil and Libby (packing house products, in export trade 40 years) write:

About the only business which we have ever done which required special packing was occasional French Government business.

The Metals Specialties Company (metal specialties) write:

We are shipping goods to all foreign countries and we do not use the metric system in any way whatsoever.

The National Radiator Company (steam radiators, boilers and fittings) write:

Our foreign customers have taken our products just as we manufacture them for domestic trade.

The Penn Engineering Company (steam and water specialties, in export trade 18 years) write:

We have never used anything except English measures, nor found any need to change them at any time.

The Russell Burdsall & Ward Bolt & Nut Company (bolts, nuts, rivets and washers; in export trade 20 years) write:

We ship our goods to almost every country throughout the world and find that the English weights, measures, etc., are generally satisfactory.

William Sellers & Company (machine tools and power transmission machinery; in export trade 60 years) write:

Notwithstanding the large volume of foreign inquiry we receive, so little of it calls for adherence to the metric system as to be practically negligible.

The Southern States Lumber Company (long-leaf yellow pine lumber, in export trade 19 years) write:

Up to 18 or 20 years ago, our French buyers required their flooring boards to be measured in metrical feet of 13¼ English inches, but since then, English measures have prevailed in that market.

The Standard Sanitary Manufacturing Company (plumbing fixtures, in export trade 20 years) write:

Our trade is using English dimensions more and more. Requisitions are now seldom written up in the metric system.

The Standard Varnish Works (varnishes, etc., in export trade 40 years) write:

We had one instance several years ago where we had to report dimensions of packages in centimeters, but that is all.

The Triumph Manufacturing Company (bakery machinery; in export trade 12 years) write:

We find that while certain foreigners have been taught the metric system they more readily adapt themselves to the English measures.

The Vacuo-Static Carbon Company (typewriter ribbons in export trade 10 years) write:

In one or two isolated cases, we have been asked to supply ribbons marked 11 mm. and 13 mm.

The Wellman-Seaver-Morgan Company (mining, hoisting, and vessel-unloading machinery) write:

We do not use the metric system in our shops, and have had practically no request to use it from our foreign customers.

The Wheeler-Schebler Carburetor Company (carburetors) write:

We have had no occasion to use the metric system in the manufacture of our products.

The Walter A. Wood Mowing and Reaping Machine Company, who reply Not at All to all of our questions, say:

We do a large export trade in Scandinavia, France, Germany, Russia, Austria-Hungary and Roumania.

LIST OF MANUFACTURERS WHO REPLIED THAT METRIC MEASURES WERE UNNECESSARY FOR THEIR PRODUCTS

Representatives of the following industries reply to the first question regarding the use of the metric system in the production of their goods for export by placing their crosses in the Not at All line. The figures in parentheses following each industry give the number of manufacturers so reporting.

The reader will note especially the number of chemical industries in this list which show that manufacturing, as distinguished from laboratory work, chemistry is conducted on the English system. The numerous electrical industries which follow the English system show that the prevailing impression that the electrical is a metric industry is unfounded.

Many of the industries of this list, such as chemicals, agricultural machinery, mining machinery, etc., produce not one, but great lines of products. Such industries, however, appear as single items, the list being not one of products, but of industries.

Automobiles and automobile trucks (22). Automobile accessories (4). Air compressors (6). Agricultural implements (18). Agricultural and harvesting machinery (9). Automobile frames (2). Automobile greases (1). Automobile lamps (1). Automobile and wagon axles (1). Air brakes (2). Automobile soap (1). Automobile parts (2). Adding machines (5). Automobile radiators (1). Automobile and wagon springs (1). Anti-skid chains (1). Asphalt (1). Athletic goods (1). Asbestos (1). Abrasives (3). Animal and poultry remedies (1). Art-metal goods (1). Aluminum goods (1). Addressing machines (1). Accounting devices (1). Artificial arms (1). Architectural terra cotta (1). Aëroplanes (1). Ammunition (1). Air rifles (1). Atomizers (1) Air hoists (1).

Boots and shoes (21). Barbers' furniture and supplies (2). Brick-making machinery (3). Bottle-washing machines (2). Bottle-blowing machines (1). Bottlers' machinery (2). Bottle-wiring tools (1). Bottle-labeling machines (1). Bedsteads, brass and iron (5). Boiler-feed regulators (1). Boiler compounds (1). Bolts, nuts and rivets (4). Biscuits (2). Balls (2). Bending machines (1). Brake lining (2). Buttons (1). Button-fastening machines (1). Ball bearings (1). Belt hooks and tools (2). Belt preservatives (1). Box strapping (1). Brazing compounds (1). Bronze bearings (1). Bags and canvas goods (2). Bicycles (1). Books (1). Boiler tubes (1). Bolt clippers (1). Bee-keepers' supplies (1). Bakery machinery (1). Braids (1). Belting (2). Brass and copper sheets, wire and other goods (6). Box shooks (1). Blankets (1). Boiler-shop equipment (1). Blast-furnace equipment (1).

Chains, including chain belting (6). Cutting tools (14). Carbon paper (3). Cranes (6). Confectionery (5). Conveying machinery (4). Carburetors (2). Cement machinery (3). Concrete machinery (8). Coal (6). Coke (4). Chemicals, including crude drugs (19). Cement including portland, rubber and iron (8). Cordage, including twine (4). Cocoa and chocolate (2). Corsets and accessories (1). Cooperage (1). Cooperage material (1). Cooperage machinery (1). Clocks (2). Corn shellers (2). Copper (2). Cotton waste (1). Cottonseed-oil machinery (1). Centrifugals (1). Cream separators (1). Check-protecting devices (1). Crockery (1). Carriages (1). Conduit for electric wires (1). Chewing gum (2). Currant-cleaning machines (1). Cars for railways (2). Cutlery (1). Cardboard (1). Coffee mills (1). Coal-handling machinery (2). Culverts (1). Children's sleds (1). Clay-working machinery (1). Catenary bridges (1). Cooking utensils (1). Crown corks (1). Chairs

(1). Car wheels (2). Car axles (1). Creosoted timber products (1). Collapsible tubes (1). Contractors' machinery (2). Caseine (1). Cotton linters, waste (1). Candles and stearine (1). Cutting machines (1). Cotton-gin machinery (1). Cigar and cigarette machinery (1). Confectionery machinery (1). Cash registers (1). Cottonseed products (1). Counting machines (2). Chemical wood pulp (1). Corduroy (1). Car couplers (1). Cotton duck (2). Conduit fillings (1). Coal-mining machinery (1). Coaster brakes (1).

Dental furniture, equipment and supplies (5). Drop forgings (1). Dyeing machines (2). Dairy machinery (2). Dustless dusters (1). Disinfecting apparatus (1). Duplicating machines (1). Drawing tables (1). Doors and sash (2). Disinfectants (1). Druggists' labels (1). Dyestuffs and dyewood products (4). Drawing rolls (1).

Electric generators and motors (14). Electric controllers (2). Electric light supplies (3). Electric specialties (3). Electric industrial trucks (1). Electric furnaces (1). Electric pumps (1). Electric-wiring devices (1). Electric wire cutters (1). Electric air compressors (1). Electric arc-welding equipment (1). Electric dental engines (1). Electric vacuum cleaners (1). Electric heating devices (2). Electric signaling apparatus (1). Electric measuring instruments (2). Electric fans (2). Electric transformers (2). Electrical fuses (1). Electrical material (1). Electrical porcelain (1). Electrically driven tools (4). Electrodes (1). Enameled physicians' furniture (1). Elevating machinery (1). Excavating machinery (1). Explosives (1). Envelopes (1). Etching material (1). Evaporated milk (1). Expanded-metal reinforcements (1). Elevators (1). Embroidery and laces (1). Engineers' and surveyors' instruments (2). Enameled ware (6).

Food products, including cereals, canned goods, packing-house, fruit and soup (24). Forging machines (2). Fans (2). Fiberboard (2). Firearms, sporting (4). Firearms, military (2). Flour (5). Feed (4). Flour-mill machinery (1). Firebrick (3). Felt (2). Food choppers (1). Fire-door fixtures (1). Feed mills (1). Feed and ensilage cutters (1). Filing cases (1). Fire apparatus (1). Fire alarm signals (1). Forges (1). Foundry equipment (2). Furnaces (3). Filters and filter presses (2). Flexible shafts (1). Fertilizer machinery (1). Flat-irons (1). Fire-resisting paints (1). Fiber conduit (1). Fair registers (1). Files and rasps (1). File-making machinery (1). Feedwater heaters (1). Floor and wall tile (1). Fireless cookers (1). Ferroalloys (1). Featherbone dress stays (1). Fly paper (1). Fuel economizers (1). Fermented liquors (2).

Grinding wheels (4). Grinding mills (1). Grinding-wheel dressers (1). Gas, gasoline, and oil engines, large and small (12). Glass, including plate, window, table, bottles, etc. (8). Gasoline-handling equipment (1). Gasoline lighting system (1). Gold-milling machinery (1). Gun carriages (1). Glass-enameled apparatus (1). Gas producers (1). Gasoline locomotives (1). Gas water heaters (1). Gas burners (1). Gas and gasoline stoves (1). Gear wheels (3). Glue (2). Gaskets and packings (1). Gas meters (1). Gravity conveyors (1). Garters (3). Graphite (1). Geared hand-brakes (1). Garbage receivers (1). Gelatin (1).

Hoisting machinery (2). Hosiery (10). Hosiery-knitting machines (1). Horseshoes (2). Handles for shovels, etc (2). Horseshoe calks (1). Hacksaw blades (1). Hydrants (1). Hot-water heaters (1). Heeling boards (1). Heat-

insulating materials (1). Hammocks (1). Hospital furniture (1). Hospital supplies (1). Hydraulic turbines (2). High-pressure hydraulic machinery (1). Hardware, including builders', carriage, upholstery, saddlery, marine and automobile (23).

Ice and refrigerating machinery (4). Ice-cream freezers (2). Ice and roller skates (1). Industrial railroad tracks (1). Irrigation equipment (1). Insulating tape (1). Insulating materials (1). Incandescent mantles (1). Insulated wire (1). Injectors (1). Iron fencing (1). Ivory goods (1).

Jewelry (5). Jewellers' tools and machinery (2). Jewellers' supplies (1).

Knit goods (2). Knitting-machine needles (1). Knitting machinery (1). Kitchen cabinets (2).

Lumber, building and cabinet (19). Leather, including upholstering, sole, patent, glazed kid, etc. (14). Leather goods (1). Leather machinery (2). Leather substitutes (1). Lubricating oils and greases (9). Lubricators and lubricating devices (4). Lifting jacks (2). Laundry machinery (3). Lawn mowers, hand, horse and power (2). Lead pencil and erasers (1). Lightning arresters (1). Lithography (1). Lithographers' machinery (1). Locks (2). Logging machinery (1). Linoleum (1). Library and parlor tables (1). Lithopone (1). Licorice products (1). Locomotives (1). Lace curtains (1). Lead (1). Lead goods (1). Loose-leaf books (2). Lockers, cabinets and shelving (1).

Machine tools (60). Machinists' chucks (4). Machinery, type not specified (18). Musical instruments (4). Marine engines and motors (4). Mining machinery (10). Metal packing (1). Mine shoveling machines (1). Malleable-iron castings (1). Metal wheels (1). Mixers (1). Metal moldings (1). Metal stampings (1). Metal-cutting saws (1). Motor boats (1). Machine screws (1). Marine paints (1). Macaroni (1). Meters (1). Metal casement windows (1). Metals and by-products (2). Motorcycles (1). Malt (1). Magnetos (1). Manganese-steel castings (1). Mower knives and sections (1). Medicinal preparations (1). Mercerizing machines (1). Medicine cabinets (1). Metallurgical machinery (1). Mosquito netting (2). Motion-picture films (1).

Nails (2). Nickel ware (1).

Office filing equipment (2). Oil-mill machinery (1). Oil-well machinery (1). Oil-well supplies (2). Oil cake (1). Oil-burning utensils (1). Oil cloth (1). Oxy-acetylene apparatus (1). Optical goods (5). Optical machinery (1). Oil-measuring pumps and tanks (1). Oiled clothing (1).

Pumps, including hand, power, centrifugal, steam and pumping engines 19). Paper of all kinds (13). Petroleum products (7). Power-transmission machinery (8). Paints, oils, varnishes and enamels (13). Pianos and player pianos (4). Pipe, including drawn and cast-iron (8). Pipe fittings (4). Pipe machinery (4). Pipe wrenches (1). Pig iron (3). Presses, mechanical (2). Printing presses and other printing machinery (6). Printing furniture (1). Picture frames and moldings (2). Pulleys, cast-iron and steel (3). Punching and shearing machines (2). Phonographs and graphaphones (2). Pneumatic tools (2). Paste and polish (2). Plumbing brass goods (1). Pulverizing machinery (1). Plumbing fixtures (1). Propellers and marine specialties (1). Pads for horses (1). Power hammers (2). Plaster of paris (1). Precious metals (1). Plantation machinery (1). Pottery (1). Plumbers' earthenware (1). Paper boxes (2). Paper-mill machinery (5). Paper-hangers' tools

(1). Paper merchandise (1). Painters' tools and supplies (1). Pharmaceutical and proprietary medicines (3). Pharmaceutical machinery (1). Padlocks (1). Pulp-mill machinery (1). Pile drivers (1). Positive-pressure blowers (1).

Quarry and gravel-pit machinery (2).

Rubber goods, including automobile tires, belting, heels, footwear, etc. (11). Rolling-mill machinery (4). Rock-crushing machinery (3). Rock drills (2). Railway track material (2). Refrigerator doors (2). Rubber-mill machinery (1). Railway signaling apparatus (1). Railway and contractors' tools (1). Railway passenger-coach fixtures (1). Railway accessories (1). Razors (1). Rawhide gears (1). Refrigerators (1). Radium, vanadium, and uranium (1). Rice milling (1). Radiators for automobiles (1). Rotary surface grinders (1). Roofing paints (1). Roofing tiles (1). Recording instruments (1). Rug extractors (1). Razor strops (1). Railway supplies (2). Road scrapers (1). Railway motor cars (1). Rolling store ladders (1). Road machinery (2). Roofing materials (1). Rare metals (1). Ratchet drills (1).

Steel and iron products, including billets, sheets, plates, structural steel, castings, blooms, bars, etc. (31). Steam-engine governors (2). Steam specialties (4). Shoe machinery (3). Shoe material (1). Saws (1) Stoves and ranges (3). Starch (3). Shovels, spades and scoops (2). Suspenders (2). School, theater and church furniture (2). Spirituous liquors (2). Steam boilers (11). Sugar machinery (8). Steam shovels (4). Soap (6). Steam turbines (2). Steam engines (14). Steel-plate work, other than steam boilers (9). Steam mains (1). Sugar-cane machinery (1). Soda fountains (1). Spark plugs (1). Scott tissue towels (1). Sewing thread (1). Stampings (1). Shoe lasts (1). Shirt and collars (2). Steel blocks (1). Shoe pegs (1). Scales (1). Steel rolling doors (1). Steel lockers, racks and tables (1). Slate (1). Snap fasteners (1). Sanitary enameled ware (1). Sewing machines (3). Spring hinges (1). Sample cases (1). Screw-machine products (1). Steel clothes lockers (1). Sprayers (1). Steel sash (1). Silver-plated ware (1). Stationery specialties (1). Soldering fluxes (1). Steel transmission structures (1). Safety water columns (1). Store fixtures (1). Seamless-tube-mill machinery (1). Speedometers (1). Saddlery goods (1). Safes, vaults, etc. (1). Stationery (1). Structural and ornamental iron (1). Street-lighting fixtures (1). Shoe manufacturers' supplies (1). Shoe dressings and polishes (3). Storage batteries (2). Sadirons (2). Scientific instruments (2). Steam radiators (2). Sawmill machinery (5). Steel ships (1). Sugar (2). Shoe laces (1). Spelter (1). Spring mattresses (1). Spark coils (1). Steel-works equipment (1). Sandpaper (1). Silos (1). Steel furniture (3). Steel tubing (1). Storage-battery cutters (1). Steam dredges (1).

Textiles, including cotton, woolen and silk (13). Textile machinery (9). Tobacco in various forms (7). Tobacco machinery (3). Typewriters (5). Toy guns (1). Tire filler (1). Type-casting machines (2). Tannery machinery (2). Tannery extracts (2). Toilet articles (3). Tin and tern plate (4). Tin ointment boxes (1). Trunks (1). Table and shelf oilcloth (1). Tire fabrics (2). Time-recording devices (1). Telephone equipment (2). Tacks, nails and rivets (1). Thermos bottles (1). Trench-excavating equipment (1). Tank cars (1). Tractors (4). Typewriter ribbons (4). Telephone-ringing machines (1). Timber-preserving machinery (1). Toothpicks (1). Tungsten contact points (1).

Underwear (4). Upholstered furniture (1). Undertakers' supplies (1).

Valves (5). Vacuum machinery (2). Vacuum cleaners (2). Veneers (3). Vises (1). Vegetable-paring machines (1). Vehicle springs (1). Vehicles for children (1). Ventilating apparatus (1).

Woodworking machinery (8). Windmills (3). Wire (5). Wagons (6). Wagon and carriage wheels (1). Wire rope (2). Wire fabrics (3). Wire products (2). Wire glass (1). Wrenches (2). Wooden mallets (1). Well supplies (1). Writing inks (1). Well-drilling machinery (2). Window fixtures (1). Wall paper (1). Water heaters (1). Wood screws (1). Wood finishes (1). Wheelbarrows (1). Waterworks material (1). Wooden boxes (1). Washing machines (1). Watchman's signals (1). Wooden ships (1). Wall board (1). Watches (4). Watchcases (1). Wood heels (3).

Zinc products (1).

Products not named (88).

PARTIAL USE OF THE METRIC SYSTEM IN PRODUCTION

The reports of partial use are, in some respects, the most instructive of all. From them, we learn that it is only in rare cases that the units of measure used in the production of a commodity have anything to do with its salability in any market, the calls for the metric system being always special and of no general application or significance.

Foreign purchasers of automobiles, electrical, mining, ice-making, agricultural machinery, etc., care no more about the units to which the parts of these machines are made than the reader cares about the English or metric units used in the construction of his own watch. The only exception to this law is found in about one-third of the reports for machine tools. Here the metric features called for are those few immediately concerned in measuring the products made on the machine.

Again, in the case of chemicals, it must be clear that the units used in the productions of the goods have nothing to do with the salability of the products. In steel and iron products — structural material, pipe, etc. — the preponderance of English-speaking countries in the production of these goods has made their products the standard of the world as is true, also, of automobile tires; while in textiles, the letter of the American Printing Company (page 430) saying that "practically all of our goods for export trade are measured in yards," shows the extent to which the yard is used as a price unit in metric countries.

The most striking illustration is found in weighing and measuring instruments designed for weighing in metric units. In these instruments the construction remains strictly English, the only metric feature being the graduated dial or scale by which the indications

are read; and in the case of recording instruments, these graduations are placed on ruled sheets of paper which are not even parts of the instruments.

Representatives of the following industries reply to the first question by placing their crosses in the Not at All, Slightly, Considerably or Exclusively lines as indicated by the figures in parentheses.

Automobiles and automobile trucks: Not at all (22), Slightly (20), Considerably (2).

The use of the metric system in the automobile and automobile truck industry to meet the needs of export trade is limited to speedometers, sparks plugs, tires and wheel rims to suit the tires. Speedometers are graduated to read in kilometers just as, for Russia, they are graduated to read in versts. In both cases, we give the customer what he wants and one practice has as much and as little significance as the other.

It will be observed that most of the automobile companies who use the metric system at all place their crosses against "Slightly" for the use of the metric system for these items. The extent of this use is shown by the following extracts from letters.

The Cadillac Motor Car Company say:

Until a year ago millimeter sized wheels and tires were shipped with cars to Australia, but our distributor there changed to inch sizes. Most South American countries take inch sizes, with the exception of Chile which takes millimeter.

The Dart Motor Truck Company say:

All the tires we have shipped on foreign shipments have been of American make and American sizes.

Dodge Brothers say:

We furnish the standard American tires on all our cars.

The Elwell-Parker Electric Co. say:

We have shipped trucks to Australia, N.w Zealand, France, Italy, England, Cuba, Ecuador and Canada with standard English sized tires.

The Ford Motor Company say:

Our cars for export trade are always equipped with American size tires — not metric size.

The International Motor Company say:

In all cases we have supplied tires in American dimensions such as are standard and on stock in this country.

The Lexington Motor Company say:

We use a few metric sized rims and tires, but in our business, it only serves to cause confusion.

The Maxwell Motor Sales Corporation say:

All of our cars which are exported are equipped with American sized tires.

The Paige-Detroit Motor Car Company say:

At the present time, the demand for metric wheels, rims and tires is extremely limited. Since the first of the year, we have only shipped 6 cars so equipped.

Metric spark plugs are so called because of the metric screw thread by which they are secured in place, all their other dimensions being English. Such plugs, however, are not universal in metric countries. The Cole Motor Car Company say in reference to export trade:

We use the 7/8–18 S.A.E. standard spark plug.

The J. B. Crockett Company say:

The percentage of metric spark plugs against those of standard thread as used by ourselves which are exported is about two-thirds metric — the balance, 1/8, 1/4 inch and 7/8 inch, that is, omitting the regular Champion X Ford plugs. The greater portion of Ford spark plugs shipped into foreign countries are the same as the regular standard American used here.

The Paige-Detroit Motor Car Company say:

Occasionally, we get a request that the spark plug be metric, with which request we comply. This is practically obsolete at the present time, owing to the predominance of American spark plugs, and we have not made shipment of a single car so equipped for over 18 months.

Dodge Brothers say:

We are shipping about $1,000,000 annually to countries which use the metric system. All of these cars go with our standard English thread spark plugs.

Automobile crankshafts: Slightly (1). The Automobile Crankshaft Corporation (in export trade three years) who make this report, say:

About 60 per cent of crankshafts we are making for export are in English measurements, 20 per cent in English and metric [that is some dimensions English and some metric] and 20 per cent in metric only.

Athletic goods: Not at all (1), Slightly (1). A. G. Spalding and Brothers (in export trade 20 years) who make this last report, say:

We have one or two pieces of apparatus used in physical measurement which we are requested, although very seldom, to make specially to the metric system.

Agricultural machinery: Not at all (9), Considerably (1), Slightly (1). The Avery Company (in export trade 20 years) who make this

last report, say that the use of the metric system relates to "Spark plugs and small equipment."

Abrasives and sharpening stones: Not at all (3), Slightly (1). The Pike Manufacturing Company (in export trade nearly 50 years) who make this last report, add the word "very" after slightly, and say:

It would be rather hard for us to estimate the percentage of orders rendered to us in the metric system, but are safe in saying it would be a fraction of 1 per cent.

Ammunition: Not at all (1), Extensively (2).

Belting: Not at all (2), Slightly (4), Considerably (1), Extensively (1). The Detroit Oak Belting Company (in export trade three years) who report "Considerably," say:

Some customers specify lengths in meters and widths in inches.

The Missouri Belting Company (in export trade 22 years) say:

We make leather belting in metric dimensions on special orders only.

The Rossendale-Reddaway Belting and Hose Company who report "Extensively," say:

We do not use it at all as far as the actual manufacturing is concerned. We do, however, receive many inquiries and orders from other countries in which they request length, breadth and thickness of belting according to the metric system, and in filling the orders, we supply them with the nearest measurements we have in feet and inches.

Brass and copper goods: Not at all (6), Slightly (2), Extensively (1). The Bridgeport Brass Company (in export trade 25 years), who report "Slightly," say:

We have furnished during the last two or three years large quantities of brass disks for the manufacture of cartridge cases, the dimensions of which were specified in metric units. These metric units we simply translated into the corresponding English equivalents and proceeded with the order. We have made seamless tubes in a similar manner and several million copper bands for shrapnel.

C. G. Hussey & Co. (in export trade 60 years) who also report "Slightly," say:

Goods are shipped to metric countries in both millimeter and English sizes. We should say, roughly, that the English sizes amount to about 75 per cent.

Bolts, nuts and rivets: Not at all (4), Slightly (3). Boiler tubes: Not at all (1), Considerably (1). Ball bearings: Not at all (1), Slightly (1). Balls: Not at all (2), Considerably (1). The Hoover Steel Ball Company (in export trade 3 years) who make this last report, say:

We do not have a very large call for the metric sizes and presume this would not amount to more than 5 per cent of our entire export orders.

Brick: Slightly (1). Boiler tube cleaners: Considerably (1). The William B. Pierce Company (in export trade 19 years) who make this last report, say:

In countries using the metric system we merely use that system for turning and measuring the outside diameter of the machine.

Boat oars, hardwood dimension stock, etc.: Slightly (1). The Anchor Sawmills Company (in export trade 60 years) who make this report, say:

It is very rarely that boat oars are ordered by the metric system as the English foot is used as the unit of length all over the world.

Cutting tools: Not at all (14), Slightly (4), Considerably (5). The Cleveland Twist Drill Company (in export trade 30 years) who report "Considerably," say that to France, Sweden, Italy and Spain their shipments are 90 per cent to 100 per cent metric. Shipments to Norway, Holland, Denmark and Russia are about 50 per cent English and 50 per cent metric. Shipments to Japan are about 90 per cent English and 10 per cent metric. Shipments to Central and South America are 95 per cent to 100 per cent English. The Detroit Twist Drill Company (in export trade 8 years) say:

All of our South American customers use more English sizes than metric. Some of the French, Italian, Swedish, Norwegian, Russian, in fact, most all of our customers of Continental Europe use some proportion of English sizes.

The National Tool Co. (in export trade 3 years) who report "Considerably," say:

In most every case we have used both the millimeter and English sizes and approximately the percentage would be 50.

The Modern Tool Company (in export trade 14 years) who report "Slightly," say:

According to our records about 10 per cent of the tools supplied to metric countries are required in millimeter dimensions.

The Murchey Machine and Tool Company (in export trade 3 years) who report "Slightly," say:

About one-tenth of our export business is in millimeter sizes.

There are two types of cutting tools — those which by their own size determine the size of the work done by them (twist drills, reamers, taps, dies, milling cutters for gear teeth, etc.) and those which do not (most mechanics' hand tools). The replies showing the use of the metric system relate to the former type in all cases.

The remarks under weighing and measuring instruments below apply here almost without change. Sizing tools of millimeter dimensions are not made for use at home, but to sell for use abroad.

In 1916 a report on The Metric System in Export Trade was issued from the Bureau of Standards. Of thirty-three pages of illustrations of American metric products, twenty-seven show weighing and measuring instruments and sizing-cutting tools made for sale and use abroad, while three of the remaining six illustrations show lathes so arranged that others may cut metric screws when necessary, but every one of them fitted for cutting English screws as a primary function with makeshift translating gears to make possible the cutting of metric screws.

To those who do not understand, the illustrations make an impressive showing of the progress of the metric system; to those who do, they make an equally impressive showing to the contrary.

Many of these tools and instruments are of American invention. Metric countries learn of their merit and call for them. We adapt them to the needs of such customers by suitably spacing and numbering the divisions by which their indications are read.

Chemicals: Not at all (19), Slightly (1), Extensively (1). Chemical machinery: Extensively (1). The Werner and Pfleiderer Company, who report "Extensively," say:

> When originally starting here in this country, we took over a number of patterns and drawings in metric which we have used ever since.

Corsets: Not at all (1), Slightly (2), Considerably (1). Car wheels, chilled rolls, and roll-grinding machines: Not at all (2), Slightly (1). The Lobdell Car Wheel Company (in export trade nearly 50 years) who make this last report, say:

> We occasionally get orders for chilled rolls for calendering paper to go abroad and the dimensions of the journals and necks are sometimes specified in millimeters. We have also had orders for a few wheels and axles with the metric sizes specified for the axle and hub dimensions.

Cotton duck: Not at all (2), Slightly (1). The Elm City Cotton Mills (in export trade 10 years) who make this last report, say:

> We have shipped quite a bit of cotton duck to Cuba and there have been a few instances where they have asked for metric measurements. For the last few years probably 95 per cent of the shipments we have made have been billed and branded with the usual English measurements.

Clay-working machinery: Not at all (1), Slightly (1). The American Clay Machinery Company (in export trade 37 years), who make this last report, say that this use of the system refers only to

dies and molds used in presses and other machines for making clay goods.

Candles, stearine, glycerine, etc.: Not at all (1), Slightly (1).

Drop forgings: Not at all (1), Slightly (2). The Armstrong Bros. Tool Co. (in export trade 25 years) say:

Slightly here means only on size of wrench openings for some wrenches going to the Continent of Europe.

The Billings and Spencer Company (in export trade 55 years) who also report "Slightly," say also that this use of the system refers only to "openings in machine wrenches."

Electrical machinery: Not at all (14), Slightly (1). The Westinghouse Electric and Manufacturing Company (in export trade 20 years) who make this last report, say:

Only on orders from foreign countries when they require us to follow their exact dimensions. This is required in only a very small fraction of the business taken — too small, in fact, to state in figures.

Elevators, escalators, conveying and hoisting machinery: Not at all (8), Slightly (1).

Explosives: Not at all (1), Slightly (1).

Electrical wires, cables and accessories: Extensively (1).

Firearms, sporting: Not at all (4), Considerably (1). The A. H. Fox Gun Company (in export trade 5 years) who make this last report, say:

About half of our foreign orders are received with the dimensions of the guns in the metric system.

Firearms, military: Not at all (2), Slightly (1). Fireclay products: Slightly (1). The Laclede-Christy Clay Products Company (in export trade "several" years), say:

On one of the inquiries we received, the size of the material required was shown in kilos and our quotation was made on the same basis. The order, however, has not been received.

Filters: Not at all (2), Slightly (1).

Glass, including plate, window, jars and bottles: Not at all (8), Slightly (2). The Pittsburgh Plate Glass Company (in export trade 3 years) who make one of these reports, say:

We have only one customer (located in Mexico) who insists upon the metric system.

Ground-steel shafting: Slightly (1). The Cumberland Steel Company (in export trade 20 years) who make this report, say:

number) are cut to metric pitches and the dials graduated to read in millimeters with no other change in the machine.

Of a special class are lathes because of their important function in cutting screws and this function has been a storm center of this controversy from the beginning. For this purpose lathes are fitted with lead, guide or master screws from which screws of other pitches are cut by the aid of combination or change gears.

How few metric countries call for any metric features of machine tools is shown by the following remarks by machine-tool builders. Except for lead and adjusting screws, which a few metric countries call for on some machines, the requirements are insignificant. About two-thirds of the replies show no metric features whatever to be asked for.

The Automatic Machine Company (automatic threading lathes; in export trade 12 years) say:

> We furnish the various countries of Europe with our standard lead screw with the exception of France, Spain and Italy to which three countries we furnish the lathes with metric lead screws.

Baker Brothers (keyway cutting machines; in export trade 20 years) say:

> We furnish some cutting tools in metric widths for keyseats, but the majority are furnished in English measurements even for metric countries.

The E. W. Bliss Company (metal-working machinery; in export trade 40 years) say:

> We do not often find it necessary to make any part of our machines to metric measurements. Occasionally, some part, where tools already existing must fit, is required to be made to dimensions in millimeters.

The Cincinnati-Bickford Tool Company (drilling machines; in export trade "many" years) say:

> We use metric speed and feed plates and give metric graduations on spindle sleeves or dial depth gages.

The Cincinnati Gear Cutting Machinery Co. (gear-cutting machines; in export trade 9 years) say:

> For European countries we furnish a metric elevating screw for the work arbor and cutter arbor of metric diameter. All other dimensions are English.

The Cincinnati Milling Machine Company (milling machines; in export trade 20 years) say:

> This applies to the feed screws which, for metric countries, are made so that the dial reads in millimeters instead of thousandths of an inch. Some metric

countries require cutter arbors made to metric diameters. Other countries, notably France, require cutter arbors made to the inch standard.

The Cincinnati Planer Co. (planers and boring mills; in export trade 19 years) say:

Never called on for any changes except some graduated dials and screws to be made metric.

The Detrick and Harvey Machine Company (planers, horizontal boring machines, gun lathes, etc.; in export trade 25 years) say:

Only in the matter of furnishing metric reading scales on certain machines. We have sold machinery in England, France, Germany, Russia, Italy, Holland, Norway, Japan, South Africa, Chile, and other foreign countries.

The Gleason Works (gear-cutting machinery) say:

The only use we make of metric dimensions in our work is when we manufacture adjusting screws to metric standards to be used in conjunction with metric scales which show relative movements of parts of the machines.

The Kempsmith Manufacturing Company (milling machines; in export trade 20 years) say:

All machines for export to France are furnished with metric screws and dials. Otherwise our machines are built to English measurements.

The Landis Tool Company (cylindrical grinding machines; in export trade 20 years) say:

Not over 5 per cent of our foreign customers require metric measures.

The Lees-Bradner Company (in export trade 4 years) say:

We supply metric lead screws to France only.

The Lodge & Shipley Machine Tool Company (engine lathes; in export trade 25 years) say:

The only metric dimensions used on the parts of any of our products are the lead screws which are made in the metric system on lathes shipped into France only.

The Lucas Machine Tool Company (horizontal boring machines; in export trade 14 years) say:

To the extent of furnishing, in those cases specified, metric traversing screws and dials graduated in millimeters and speed and feed plates reading in millimeters instead of inches.

The Morris Machine Tool Company (lathes and radial drills; on export trade 10 years) say:

Occasionally, we furnish lathes to cut metric pitch threads.

The Norton Grinding Company (cylindrical grinding machines; in export trade 16 years) say:

There are four small parts of our grinding machines that we make to metric measurements for a few customers in some European countries.

The Rockford Drilling Machine Company (drilling machines; in export trade 17 years) say:

Metric dimensions are stamped on drilling-machine quill on machines for certain foreign countries.

The Springfield Machine Tool Company (lathes and shapers; in export trade 25 years) say:

Metric system used only for French trade in which only the lead screw and change gears are metric.

The Warner & Swasey Company (turret lathes) say:

We have furnished on special orders screw-threading dies and chuck jaws to metric sizes.

Shortly after the beginning of the great war the *American Machinist* sent a commissioner (Mr. O. P. Hood) to South America. Mr. Hood who speaks both Spanish and Portugese made the circuit of the continent, spending 18 months at the task, and returned with substantially a census of the personnel and equipment of South American machine shops. Mr. Hood's papers show that in the machine shops of South America — of which there are more than most people realize — 39.3 per cent of the machine tools are American, 43.2 per cent are British and the remaining 17.5 per cent are German, Belgian and French. While South American shops have the world from which to buy, they choose machine tools made to English over those made to metric measures in the ratio of nearly 5 to 1. Moreover, commercial Germany has long been splendidly represented in South America, while we have never been and Germany has had ample shipping and banking facilities which we have not.

Mechanical presses: Not at all (2), Slightly (1). The Ferracute Machine Company (in export trade 35 years) who make this last report, say:

There are a few cases through our French agents where it is necessary that holes be tapped and bolts be threaded by the metric system, but in each case they allow us to furnish the bolt in blank and the hole drilled so that it can be properly tapped by the metric system and the bolt threaded by metric system after it arrives.

Magnetos: Not at all (1), Slightly (1). Machinery and equipment pertaining to the meat industry: Slightly (1).

Optical goods: Not at all (5), Slightly (2), Considerably (2), Extensively (1).

The use of the metric system in optical work applies only to the grinding of lenses, the mechanical parts of cameras, microscopes, etc., being made to the English system. The Eastman Kodak Company say:

Used only in connection with optical work, *i.e.*, lens manufacture.

The Spencer Lens Company (in export trade 10 years) say:

We do use it mostly for the lens work, but are inconsistent enough to use the English system for mechanical work.

This system was not adopted for the benefit of export trade as is shown by the following from the Eastman Kodak Company:

It is customary in this work to use the metric system of measurement, probably because the practice in U. S. A. followed foreign practice where lens optics were first perfected.

Lens manufacture is one of many examples of the manner in which an industry, when transferred from one country to another, carries with it the units of measurement on which it was developed.

Another illustration is found in shoe machinery. The United Shoe Machinery Company write:

Our company established factories in England, France, Germany and Austria, and have exported goods and maintained subsidiary companies or branch offices in practically all of the countries of South America.

In order to maintain uniformity, such machines as we manufacture both at home and abroad, the English system of measurements is used in all countries so that if necessary machines and parts may be supplied from one country to another.

Another illustration is found in machinery and appliances for the chemical trade, regarding which the Werner and Pfleiderer Company write:

When originally starting here in this country, we took over a number of patterns and drawings in metric which we have used ever since.

Again, the Whitehead torpedo carried the English inch from England to Austria; as, again, steel balls carried it from the United States to Germany. The methods of wholesale precision manufacture of balls were developed in this country and taken to Germany where the customary practice today is to make steel balls to inch dimensions — German formulæ for the carrying capacity of ball bearings containing a factor for the diameter of the balls in English inches.

In the manufacture of silk fabrics, among Western nations, France early gained the leading position and, as a result, the French

system of numbering silk based on the denier (a weight) and the aune (a unit of length) became not only the silk standard of France, but of all countries, and is today the world standard for silk. In like manner, the early dominance of England in the cotton trade has made the English system of numbering cotton yarn based on the yard and pound the standard of the world, the only exception being France where it was found impossible to force the metric system based on the kilometer and kilogram on the cotton trade, the result being a compromise by the adoption of a system based on the kilometer and metric pound, the numbers of which were, approximately, but one-sixth less than those to which the trade had been accustomed.

Equally striking, is the establishment as world standards of the English standards for numbering linen and jute yarn.

But the most impressive example of the spread of standards of measurement as a result of industrial development is presented by Russia, whose system of linear measurements is based on the English inch and foot as a result of the visit of Peter the Great to England about 1701. Working in the English shipyards, the Russian Czar was impressed by the skill of English mechanics and when he returned home took with him a number of English workmen to introduce their trades in Russia. In doing this, they also introduced the English inch and foot which are now in general use throughout that great area known as Russia. The Russian duim is the English inch; the Russian foot is the English foot; the arshine is 28 inches; the sagene is 7, and the verst is 3500 English feet. All these are standards that will survive revolutions and invasions and are, with the language, the most stable of the country's institutions.

Oil-mill machinery: Slightly (1). The American Machine and Manufacturing Company (in export trade 6 years), who make this report, say:

> We have to give feet, inches, etc., as well as metric measurements in some cases.

Oilless bearings: Slightly (1). The Bound Brook Oilless Bearing Company, who make this report, say:

> Only on rare occasions do we receive an order in metric measurements.

Oxygen apparatus: Extensively (1).

Power-transmission machinery: Not at all (8), Slightly (3). The Dodge Manufacturing Company (in export trade for 25 years) who make one of these reports, say:

Probably 99 per cent of our export production is made on English measurements and weights that is, inches, feet and pounds.

The Standard Pressed Steel Company (in export trade 10 to 12 years), who make another of these reports, say:

Our Pioneer steel shaft hangers are sold rather extensively to concerns throughout Europe and other markets where the metric system is used, and inasmuch as in some of these countries, shafting of millimeter diameter is used, it is necessary that we babbitt the bearings in our shaft hangers to a corresponding diameter.

The T. B. Woods Sons Company, who make the third of these reports, say:

The only places we use metric sizes in our work is in boring pulleys and other appliances which are used on line shafts.

Perforated metals: Slightly (3). The Harrington and King Perforating Company (in export trade "many" years), say:

On receipt of an order it (the metric system) is changed to the English system and thus put through the factory with a few exceptions. We often use the metric system for specifying the size of perforations in our own factory and to both foreign and domestic customers.

Pipe: Not at all (8), Extensively (1). In this case, cast-iron pipe. Platinum: Extensively (1). Paper: Not at all (13), Considerably (1), Extensively (1).

Picture frames and moldings: Not at all (2), Slightly (1).

The Indiana Moulding & Frame Company, who make the last report, say:

Very few orders received requiring lengths or sizes in meters.

Piping: Not at all (1), Slightly (1). The Ballwood Company (in export trade 5 years) who make this last report, say:

We sometimes get orders for pipe, the lengths and flanges of which have to be finished to metric dimensions.

Paper cutters: Slightly (1). The Chandler & Price Company (in export trade 20 years) who make this report, say:

On a few paper cutters, we use the metric system in graduating the brass rule on the bed.

Rubber goods, including automobile tires, hose, etc. Not at all (11), Slightly (9), Considerably (2), Extensively (1). The practice regarding automobile tires is given above under automobiles. The Boston Woven Hose and Rubber Company (in export trade 30 years) who report "Slightly" say:

The manufacture of hose for countries using the metric system is identical with the process used for hose consumed in this country with the single exception that the hose is made of a definite number of meters long instead of feet.

The Electric Hose and Rubber Company (in export trade 12 years) who report "Slightly," say:

We ship goods to metric countries made to both English and millimeter sizes, about 2 per cent of which are made to millimeters and the balance to English sizes.

The Manhattan Rubber Manufacturing Company (in export trade 20 years) who report "Slightly," say:

Some buyers in metric countries insist on metric measurements, others do not. In not more than twenty cases in a year's time goods are ordered from us with the dimensions specified in the metric system.

The Lee Tire and Rubber Company (in export trade 6 years) who report "Slightly," say:

We ship both English and millimeter sizes to South America.

The Goodyear Tire and Rubber Company who have been widely heralded as having "adopted" the metric system, say:

We are shipping tires made in both English and metric sizes to countries using the metric system. We estimate that somewhat less than 20 per cent of our total tire exports are made up of metric sizes. In addition, we are actually making partial use of the metric system in manufacturing practice, [and "partial use" is as far as they will ever get.]

Railway material: Not at all (2), Slightly (2). The National Malleable Castings Company (in export trade "several" years) say:

We have had to work from the metric system dimensions on some of the foreign blueprints that we have furnished. The use we make of the metric system is so small as hardly to be considered.

Seamless Steel Tubing: Not at all (1), Slightly (2). The Elwood Ivins Tube Works (in export trade 20 years or more) who make one of these reports say:

When any person orders tubing made by metric measure, we immediately translate it in decimals of an inch. We never bill our tubes in metric measure, billing them in decimals of an inch. It is not by any means frequent that we get orders by metric measure.

Steel and iron products: Not at all (31), Slightly (1), Considerably (2). Shackle bolts and auto accessories: Slightly (1). The Bowen Manufacturing Company (in export trade 22 years) who make this report say:

On one occasion we had to make a lot of spring-shackle bolts having a metric thread at one end.

Sugar machinery: Not at all (8), Slightly (2). The Joubert & Goslin Machine and Foundry Company (in export trade 12 years) who make one of these reports, say:

The only time that we are called upon to follow metric dimensions is where we furnish some repair parts or make some addition to a machine built in Europe.

Lewis Colwell (in export trade 20 years) who makes the other of these reports says:

Only when repairs or changes are required of installation of some foreign manufacture.

Scientific instruments: Not at all (2), Slightly (1), Extensively (1). The Brown Instrument Company say:

We build instruments [pyrometers] using both the fahrenheit and the centigrade scales. In this country probably one out of every hundred orders calls for the centigrade range.

Semi-rare ores and their products: Slightly (1). The Foote Mineral Company (in export trade 41 years) say:

We believe that less than half our foreign trade requests the marks on either invoice or packages to be in metric units, and we believe that not more than 5 per cent of it requires that the containers or goods be actually metric in character as well as in marks.

Sugar, coffee and rice machinery: Considerably (1). The Bahmann Iron Works Company (in export trade 8 years) who make this report, say:

We have considerable repair work for existing machinery in South American countries.

Steam and plumbing supplies: Not at all (4), Slightly (1). The John Simmons Company (in export trade 27 years) say:

Lengths of pipe in meters for some countries.

Springs: Slightly (1). The Mather Spring Company, who make this report, say:

We find that in general the English dimensions have proven satisfactory except in a very few cases.

Safety fuse: Slightly (1). The Ensign Bickford Company (in export trade 50 years) who make this report, say:

For export to South America and certain other countries, we are often required to measure the length of the fuse as well as given dimensions and weights in metric units.

Shirts and collars: Not at all (2), Slightly (1). Surgical, dental and hospital equipment and supplies: Not at all (7), Slightly (1).

Spark plugs: Not at all (1), Considerably (1). The New York & Brooklyn Auto Supply Company say:

According to our experience 50 per cent are shipped in metric thread and the balance in American threads.

Textile machinery: Not at all (9), Slightly (1). J. E. Windle (in export trade "several" years) says:

We have had to make measuring dials register in metric measure on several machines we have exported the past few years.

Tractors: Not at all (4), Slightly (1). The Knox Motors Company (in export trade three years) say:

Metric sized spark plugs are used in our cylinders on export shipments, also metric measure is used in some ball bearings.

Transmissions for marine explosive engines: Slightly (1). The Evans Stamping and Plating Company (in export trade six years) who make this report, say:

On shipments to Belgium to fit shafts to metric dimensions.

Tobacco: Not at all (7), Slightly (1).
Textiles: Not at all (13), Considerably (1).[1]
Stay bolts: Slightly (1).

The Flannery Bolt Company (in export trade 10 years) say:

We furnish goods to certain countries where it was necessary to state both millimeter and English sizes. We have not really furnished anything to millimeter size alone.

Tool holders: Slightly (1). The Western Tool and Manufacturing Company (in export trade 10 years) say that this refers to threading tools only.

Vulcanized fiber, Extensively (1).

Watches and watch cases: Not at all (5), Extensively (2).

The metric system was not originally applied to American watch manufacture for the benefit of export trade, but because it was believed to be better adapted to the industry. The pioneer American (the Waltham) works adopted it at an early date and have continued it. Later, the Waterbury (now the Ingersoll) Works were fitted out by men from the Waltham Works who took the metric system with them, but all other American watch works conduct their operations on the English system.

[1] The questionnaire containing this report carries an undecipherable signature, making it impossible to send a second form letter.

A parallel example is found in steam boiler injectors. This industry was imported from France by William Sellers & Company who adopted and have continued the use of the metric system, but no competitor has followed their example, all other injector factories being conducted on the English system.

Another example is found in card-indexing and filing systems. The pioneer in this industry — The Library Bureau — was founded by Mr. Melville Dewey who was a metric enthusiast and therefore adopted the metric system at the beginning. Competitors failed to follow the example of the Library Bureau, and that company has now abandoned the system.

The Library Bureau say:

> Some years ago all attempt at working to metric sizes and bringing out new cases was abandoned and the old lines were duplicated with full dimensions.
>
> Our draftsmen and mechanics failed to make any attempt to familiarize themselves with the metric system, but simply translated the metric dimensions into English inches or fractions thereof, and worked accordingly. I do recall, however, having known one man connected with Library Bureau in former days who was inclined to brag that he had mastered the metric system sufficiently so that he could actually think in it as well as he could in feet and inches, but I take it that his was a very rare case.

A fourth example is found in magnetos. The Ericsson Manufacturing Company who manufacture the Berling magneto write:

> As a matter of fact, 10 years ago we used the metric measures in this plant exclusively, but owing to inability to get American mechanics who could use the metric system, we found it necessary to shift to the English measures and they are now used exclusively by us both for our product for domestic and export manufacture.

A fifth example is found in the chemical industry of the Solvay Process Company, of which the drawings used in the construction of the first plant came from Belgium and were in the metric system. The Solvay Process Company write:

> As the workmen in this country were not used to these measures, it became necessary to translate them into the foot and inch system. In many cases this was done by using 40 inches for the meter which gave even inches. We have stuck to the foot and inch for measurements because it was too much of a task to educate all of our workmen to the other system.

It should be added, however, that the Solvay Process Company have continued to use metric measures of weight and capacity.

Here are five examples of the attempted adoption of the metric system under the most favorable possible conditions, namely, at the beginning of an industry. In two of these cases, it has been aban-

doned outright, and in the third, abandoned for measures of length.[1] In the other two cases, it has been continued in the factories where it was introduced, but it has not spread to other factories which followed them in point of time.

Moreover, those who continue to use the system because they have established an industry upon it and find the same difficulty in changing from it that they would in changing from the English system, do not find the anticipated advantages. William Sellers & Company, who introduced the system in the manufacture of injectors, write:

> Our experience with the metric system, extending over 50 years, does not encourage us to extend its use beyond the borders of the shop and the class of work for which it was originally started.

Weighing and measuring instruments including pressure gages, etc.: Slightly (8), Considerably (2). The H. W. Johns-Manville Company who report "Slightly" say:

> When we have orders for speedometers for Latin countries or Germany, we make them to show kilometers and not miles. On orders from Russia, we make them to show Russian versts and not miles. The number of instruments sold to these countries is very, very small as compared with countries using miles.

The L. S. Starrett Company (in export trade 25 years) who report "Considerably," say:

> We estimate that not more than 5 per cent of our product is in the metric system.

The Goodell-Pratt Company (in export trade 22 years) say:

> We make a few measuring instruments with metric graduations. Other than that, we use no metric measurements at all and for an average, over a period of 20 years, 40 per cent of our product has been exported.

The Richardson Scale Company (in export trade 12 years) who report "Slightly," say:

> Our scales being of the even arm type, our weights are all dead weights and it makes no difference what kind of weights are used. [Which is to say that the scales supplied to metric countries are *identical* with those supplied for home trade.]

American makers of weighing and measuring instruments have developed a large export trade and, for metric countries, they are, of course, to give their indications in metric units. For example, weighing scales of the dial type are made to read in kilograms, linear measuring instruments in millimeters and pressure gages in kilograms per square centimeter.

[1] It is well known that the great difficulty of the change centers about the unit of length.

Worm gears and lead screws: Slightly (1). The Hindley Gear Company who make this report say:

The quantity [made to metric measurements] is so slight in proportion to the amount of business we do, that we hardly know what percentage to claim — doubtful if it amounts to ½ of 1 per cent.

Products not specified: Slightly (1).

EXCLUSIVE USE OF THE METRIC SYSTEM IN PRODUCTION

One representative of each of the following industries replies to the first question by placing his cross in the Exclusively line:

Carbon products (1), proprietary medicines (1), coin-operated machines and violino virtuoso instruments (1), piston-head packing rings for automobiles (1), drills, reamers and tools (1).

THE SECOND QUESTION

We have found it advisable to pack our goods for trade with metric countries in containers of metric dimensions or containing metric weights to the following extent.

The use of the metric system disclosed by the second question, while of trifling importance as compared with the use covered by the first question, is even more instructive as a means of showing the slight call for its adoption for the benefit of export trade.

This question was intended to cover those goods which are shipped in tin cans, pasteboard boxes and other containers of definite metric weight or capacity.

Following is a summary of the replies to the second question.

TABLE 2 SUMMARY OF REPLIES TO THE SECOND QUESTION

	Count of returns	Per cent
Not at all	746	51.6
Slightly	24	1.7
Considerably	16	1.1
Extensively	13	0.9
Exclusively	1	Negligible
Give metric weights and, in a few cases, dimensions on shipping cases and bills of lading	546	37.9
No reply to this question	99	6.8
Total	1445	100.00

Replies to the number of 106 place the cross for the second question in the Not at All line, and follow this under Remarks and Particulars with the statement that they make out shipping documents and give weights of shipping parcels in metric units. Such replies are clearly a discrimination between metric containers and the giving of weights of shipments in metric terms, and, in the intended meaning of the second question, should be included in the Not at All replies. This, however, has not been done, all such replies being included in the classification of those who give metric weights on shipping cases and bills of lading.

The questionnaire was not framed to bring out the effect of the laws of foreign countries on shipping methods and, had it been so framed, no definite summary of the facts could have been obtained because the extent of this use of metric units in the case of any shipper depends upon the countries to which he makes shipments. However, many remarks upon the papers throw light upon this phase of the subject. Of these, the following are typical examples:

In a small part of our shipments, we find it necessary to give the weights in kilograms. (In export trade 10 years.)

In some instances we have had to make crates with metric dimensions and weights, and have given metric dimensions on invoices. (15 years.)

We sometimes mark tags and boxes with the metric system.

Possibly 2 per cent of export shipments. (10 to 15 years.)

This is not required on more than 10 per cent of our export shipments. (25 years.)

In some instances we have been requested to put the weights in the metric system as well as our own. (135 years.)

They [metric units] are used in this connection but slightly. (A great many years.)

Only a very few times. (8 years.)

We have only made two or three shipments during the past year where they required us to weigh the articles in kilos. (3 years.)

The number of these requests have been few.

In a few cases, we have been asked to mark our cases using the metric system for weights and measurements. (5 years.)

This, however, was done only in possibly a half-dozen instances. (3 years.)

Crates marked with weights in kilos in a few shipments. (8 years.)

We have been called upon to pack goods according to metric weights and dimensions to a small extent. (2 years.)

We have not found it necessary to use metric dimensions and metric weights on more than three or four occasions. (12 years.)

In a very few instances, we are asked to give weights to the customer in kilos. (25 years.)

In shipping, we are sometimes required to mark weights of cases in kilos (40 years.)

In some cases, mark export packages with metric weights.

Occasionally, besides the English net and gross weights, we are requested also to give the kilos. (9 years.)

Sometimes asked to give all particulars of weights and measurements in metric figures. (60 years.)

For customs purposes in a very few instances. (12 years.)

Occasionally we have a request to give size of crate and weight of shipment in advance in the metric system. (15 years.)

Applies to about 1 per cent of our shipments. (20 years.)

Occasionally requested to give not only the weights in kilos, but also the metric measurements of the packages. (10 years.)

This applies to dimensions of packing cases which all countries accept from us in cubic feet and cubic inches. (10 years.)

The request for use of the metric system is not general or universal from all our customers in any one country. Some customers require it, while others in the same country do not. (30 years.)

In a few instances, weights in kilos have been required. (25 years.)

Only on rare occasions. (20 years.)

In a few cases we have been asked to give weights in kilograms. (25 years.)

Weights of shipments and dimensions of packages in a very few cases were given in metric units. (30 years.)

Occasionally, when so specified. (More than 30 years.)

Very seldom are we required to use the metric system. (30 years.)

Occasionally we give weights of cases in kilos. (20 years.)

In a very few instances. (20 years.)

We occasionally have to state weights in kilos. (30 years.)

Weights in kilos, sometimes. (20 years.)

Requests come very infrequently. (17 years.)

Occasional marking in kilograms. (20 years.)

Sometimes have to do this. (15 years.)

Only in rare instances. (15 years.)

Metric system used only in occasional shipments. (10 years.)

Only on one shipment have we ever been asked to give metric measurements. (15 years.)

Occasionally, besides the English net and gross weights, we are requested to also give the kilos. (15 years.)

We sometimes mark the cases with weights and measurements in the metric system. (10 years.)

In remote instances have given the weight in kilograms, (10 years.)

In a few instances, we have had to state weights in kilos. (5 years.)

We are occasionally requested to mark weights in kilos. (6 years.)

We sometimes give weights in kilograms. (Several years.)

A few weights in kilos only.

We are occasionally called on to convert our shipping weights to kilos on export shipments. (4 years.)

In some cases where customers request it we stencil on outside of cases metric measurements. (25 years.)

Ship both English and metric containers to the same countries. (Almost a century.)

Have several times shown metric dimensions, weights, etc., on invoices and cases. (20 years.)

Occasionally give weights of shipments in kilograms. (30 years.)

Many more similar quotations could be given but the above are sufficient.

THE THIRD QUESTION

In our literature for, and correspondence with, metric countries, we have found it advisable to give information regarding weights, output, capacities, overall dimensions, etc., in metric terms as follows:

TABLE 3 SUMMARY OF REPLIES TO THE THIRD QUESTION

	Count of returns	Per cent
Not at all	835	57.8
Slightly	279	19.3
Considerably	114	7.9
Extensively	78	5.4
Exclusively	38	2.6
No answer to this question	101	7.0
Total	1445	100.00

The use of the system covered by the third question involves, in the case of machinery, no more than the giving of capacities, weights and overall dimensions in metric equivalents; in the case of structural materials, the giving of weights in kilograms per meter instead of pounds per yard, with leading dimensions of sections in approximate metric equivalents; and in other cases the giving of prices per kilogram or per liter instead of per pound or per gallon.

Why do but 42 per cent of our exporting manufacturers find occasion to make any use of the system and but 8 per cent of them to make extensive or exclusive use of it in this simple way? Because buyers in other countries understand our units precisely as we understand theirs — but better.

CONCLUSION

The conclusion is that the export trade of the United States is conducted by the English system. From Table 1 (page 429), we learn that 82 per cent of our exporters to metric countries use the metric system not at all in production, while 14 per cent use it partially and in ways that, when explained, are inconsequential; and $\frac{4}{10}$ of 1 per cent really use it exclusively.

No. 1652

MEETINGS SEPTEMBER–DECEMBER

MEETINGS OF SECTIONS

DURING the last six months of 1918, forty meetings were held by twenty-one organized Sections of the Society and the Providence Engineering Society, an affiliated body. Six of these meetings were arranged jointly with one or more local technical organizations or branches of other national engineering societies in different centers. A number of the papers of more general interest which were presented at these meetings were published in THE JOURNAL during 1918 and in MECHANICAL ENGINEERING during the early months of 1919.

ATLANTA

October 17: Paper on Uniform Boiler Code, E. A. Brooks. Abstract published in THE JOURNAL, December 1918.

November 26: Discussion of local affairs.

December 27: Report of chairman covering his recent trip to New York as the Section's delegate at the Annual Meeting; also report of Atlanta delegate to Committee on Aims and Organization.

BALTIMORE

November 20: The Design of Hopper Bottoms for Coal Bins, A. E. Walden; Marine Practice in Valves and Piping, A. G. Christie, published in MECHANICAL ENGINEERING, February 1919.

December 18: Electric Furnaces as Applied to Steel Making, Henry Hess, published in MECHANICAL ENGINEERING, March 1919.

BIRMINGHAM

September 9: Organization and business meeting.

October 24: The Manufacture of Raw Sugar, E. H. Rousseau, illustrated with balopticon views.

November 20: Dinner, followed by a general, informal discussion.

BOSTON

October 29: Papers on Elements of the Labor Problem, F. P. Fish; and on Government Activity Toward the Solution of the Labor Problem, W. E. Freeland.

November 9: Lecture by A. Douglas Wardrop on his trip to France and experiences on the fighting line.

December 19: Subject: Fuel, with address by David Moffat Myers on Results of Fuel Conservation. Remarks also by Perry Barker, followed by a motion picture entitled Coal is King.

BUFFALO

November 27: Address on Bearings, C. H. Bierbaum.

CHICAGO

November 12: Joint meeting with Chicago Section of A.I.E.E. and the Western Society of Engineers. Subject: Industrial Lighting and the War, illustrated by lantern slides, by Prof. C. E. Clewell.

December 13: Dinner meeting. Address by D. L. Derrom on Shell Manufacture.

CINCINNATI

November 12: Joint meeting with Engineers' Club. Subject: Readjustment of Industries to Peace Conditions, with addresses by A. J. Baker and Prof. J. D. Magee. Abstract of Professor Magee's address published in MECHANICAL ENGINEERING, April 1919.

CLEVELAND

October 4: Newly established Section organized and officers elected.

November 29: Special meeting to discuss and recommend a plan whereby the various branches of engineering might be united under one head both nationally and locally.

CONNECTICUT

Bridgeport Branch

September 9: Luncheon, at which Charles A. Otis delivered an address on Industry and the War.

December 18: Subject: Industrial Management, with addresses by J. C. Spence on Vestibule Schools; Prof. H. B. Bogell on The Education of the Radio Operators in Connection with Airplanes; and A. W. Lebouef on Shop Education.

New Haven Branch

November 20: Fall meeting. Inspection trip followed by dinner and evening session at which W. H. Blood, Jr., gave an illustrated address on the Building of Hog Island Shipyard.

Waterbury Branch

November 25: Luncheon meeting, at which officers were elected for fiscal year.

DETROIT

September 6: Address on the Hog Island Shipyard, by H. H. Esselstyn.

September 20: Paper on Recent Progress in Bridge Construction, Prof. Henry S. Jacoby.

ERIE

November 25: Address on the Glacial History of Lake Erie, by E. J. Armstrong.

MILWAUKEE

September 11: Illustrated address on The Work of the Bureau of Standards, with Special Reference to Local Electrolysis Surveys, E. R. Shepard.

MINNESOTA

September 3: Organization meeting.

October 7: Paper on By-Product Coking, Particularly in Its Relation to the Steel and Iron Industry, F. W. Sperr, Jr.

December 17: Illustrated lecture on Mining Iron Ore in Minnesota, Prof. E. H. Comstock.

NEW YORK

September 17: Marcel Knecht, member of the French High Commission in the United States, addressed the meeting on The Supreme Effort of the French War Industries — Franco-American Industrial Coöperation During and After the War.

November 20: Joint meeting with other technical societies. Addresses by Albert C. Ritchie, Captain P. E. Dulieux and Julius Kahn.

ONTARIO

November 29: Illustrated address on the Main Pumping Station of the Toronto Water Works, John Milne.

PHILADELPHIA

September 24: Illustrated address by W. H. Blood, Jr., on The Making of Hog Island, The Greatest Shipyard in the World.

November 26: J. F. Johnson delivered an address on Large Steam Turbine Design. Abstract published in MECHANICAL ENGINEERING, April 1919.

PROVIDENCE

November 8: Address by A. Douglas Wardrop on My Flight Over the Hindenburg Line, and Latest Developments in Aërial Warfare.

November 19: Illustrated lecture by Major Frank B. Gilbreth on the mechanical action of the new designs of Lewis and Browning machine guns.

December 17: Address by W. H. MacKay on Marine Engineering and Up-to-Date Methods of Repairing Ships.

ST. LOUIS

September 27: J. A. Whitlow addressed the meeting on Fuel Conservation.

SAN FRANCISCO

September 26: Joint meeting with the Local Sections of the A.S.C.E., A.I.M.E., A.I.E.E. and A.C.S. under auspices of A.S.M.E. Section. Subject: Fuel Conservation, with addresses by Albert E. Schwabacher, A. H. Markwart, D. M. Folsom, John A. Britton, H. G. Butler, P. M. Downing, Harry S. Markey, Major George F. Sever, W. J. Davis and Prof. Edmund O'Neill. Abstracts published in MECHANICAL ENGINEERING, March 1919.

December 16: Luncheon meeting. Paper on the Use of Pulverized Coal, by M. C. M. Hatch.

December 19: Subject: Why is the Internal-Combustion Engine Not Used More Extensively for Marine Propulsion? Illustrated address by J. H. Hanson, covering history and development of the Diesel engine; papers by George A. Dow on the Diesel Oil Engines on Board the Motorship *Libby Maine;* and by Bruce Lloyd covering the attitude of ship owners toward the use of the internal-combustion engine as power for the propulsion of ships. Abstracts published in MECHANICAL ENGINEERING, April 1919.

THE ANNUAL MEETING

THE thirty-ninth Annual Meeting of the Society, held December 3 to 6, was a meeting simply conducted in accord with the spirit of the times, yet an occasion of very genuine pleasure to the large number in attendance. The total registration was 1717, of whom 1040 were members.

The convention opened on Tuesday evening, when President Main delivered his address on Broader Opportunities for the Engineer, which was followed by the conferring of Honorary Membership upon Charles M. Schwab and Orville Wright. Lectures of wide appeal, covering some of the important engineering work of the Army and Navy, were given on Wednesday and Thursday evenings, the Thursday evening lecture being followed by the customary reunion and dance. At a luncheon held on Wednesday, Dr. George W. Kirchwey, formerly Dean of the Columbia Law School, gave an address entitled A Message from the Legal Profession.

On Monday and Tuesday of the convention, the Committee on Aims and Organization held several conferences, the conclusions of which were summarized in a progress report presented at the Business Session on Wednesday morning.

Special entertainment provided for the ladies consisted of a reception and tea on Wednesday afternoon. The Excursion Committee arranged for several excursions, among them being an inspection of the concrete steamship *Faith*.

The Committee on Meetings and Program, in charge of the convention, sensing the spirit of the times in relation to labor problems, planned an all-day session on the human elements that enter into these problems. This session was introduced by Dr. L. S. Rowe, Assistant Secretary of the Treasury, who was followed by other speakers who dealt with various phases of the employment question. A strong session was arranged by the Sub-Committee on Machine Shop Practice, at which papers were presented reviewing the work of standardization accomplished by the British Engineering Standards Association and of practice in this country in thread-gage making and testing.

A joint session was also held with the American Society of Refrigerating Engineers, to which both societies contributed papers, and an interesting session in charge of the Sub-Committee on Textiles dealt with problems confronting mill engineers. There were

also the usual general sessions at which papers of a miscellaneous character were presented.

The meeting concluded on Friday morning with a brief service of a religious character, addressed by Rev. Edmund M. Wylie, of Montclair, N. J., who had been in charge of Y. M. C. A. work in Great Britain and who had visited the whole of the Western Front. The concluding session of the previous Annual Meeting had ended in silent prayer that another year might find our boys on the way home after a glorious victory. This hope had been realized and it was deemed fitting that the 1918 meeting should be closed by a few words from one who had gone to St. Mihiel with one of our divisions and had been present at that great victory.

There were the usual alumni reunions, held by eight colleges.

The Chairmen of the various committees responsible for the success of the meeting were as follows: L. P. Alford, Committee on Meetings and Program; W. W. Macon, Chairman and George K. Parsons, Acting Chairman of New York Local Committee, in charge of entertainment features; James W. Nelson, House Committee, which directed the President's Reception; L. L. Brinsmade, Acquaintanceship and Badge Committees; Edric B. Smith, Caterer's Committee; Maxwell M. Upson, Dance Committee; H. J. Marks, Excursion Committee; Henry A. Lardner, Invitations for Army and Navy Night; Mrs. Jesse M. Smith, Ladies' Reception committee.

PROGRAM

Tuesday Morning, December 3

Registration of members and guests.

Tuesday Evening

PRESIDENTIAL ADDRESS AND RECEPTION

President's address: BROADER OPPORTUNITIES FOR THE ENGINEER, Charles T. Main. Conferring of Honorary Membership upon Charles M. Schwab and Orville Wright.

Reception by the Society to the President, President-elect, ladies, members and guests.

Wednesday Morning, December 4

BUSINESS MEETING

Discussion on Amendment to Constitution, Reports of Committees.

Preliminary Report of Committee on Aims and Organization.

LUNCHEON

Address: A MESSAGE FROM THE LEGAL PROFESSION,[1] by Dr. George W. Kirchwey.

[1] Abstract published in MECHANICAL ENGINEERING, January 1919.

Wednesday Afternoon

SIMULTANEOUS PROFESSIONAL SESSIONS

MACHINE-SHOP SESSION

THE BRITISH ENGINEERING STANDARDS' ASSOCIATION, C. le Maistre.

WORK OF THE BRITISH ENGINEERING STANDARDS ASSOCIATION ON SCREW THREADS AND LIMIT GAGES, Sir Richard Glazebrook.

PRESENT PRACTICE IN THREAD-GAGE MAKING, Frank O. Wells.

MEASUREMENT OF THREAD GAGES, H. L. Van Keuren.

STANDARDS FOR LARGE TAPER SHANKS AND SOCKETS, Luther D. Burlingame.

REFRIGERATION SESSION

THE DEVELOPMENT OF A STANDARD REFRIGERATOR CAR, Mary E. Pennington.

Address[1] by David Moffat Myers, Advisory Engineer, U. S. Fuel Administration.

REFRIGERATING PLANT EFFICIENCY, Victor J. Azbe.

RECEPTION AND TEA

Given by the Ladies' Committee in the Engineering Societies Building.

Wednesday Evening

Lecture on THE ACHIEVEMENTS OF NAVAL ENGINEERING IN THE WAR, with special reference to the Bureau of Steam Engineering of the Navy Department, Lieut.-Commander William L. Cathcart, U.S.N.R.F.

THE 50-CALIBER 14-INCH NAVY GUNS WITH RAILWAY MOUNT, Lieut.-Commander D. C. Buell, U.S.N.R.F.

Thursday Morning, December 5

FIRST SESSION ON ENGINEERING OF MAN POWER

THE ENGINEER IN FOREIGN SERVICE,[2] Dr. L. S. Rowe, Assistant Secretary of the Treasury.

INDUSTRIAL ORGANIZATION AS IT AFFECTS EXECUTIVES AND WORKERS, C. E. Knoeppel.

STANDARDIZATION AND ADMINISTRATION OF WAGES,[2] Henry P. Kendall and Earl Dean Howard.

NON-FINANCIAL INCENTIVES, R. B. Wolf.

Thursday Afternoon

SIMULTANEOUS PROFESSIONAL SESSIONS

SECOND SESSION ON ENGINEERING OF MAN POWER

THE EVOLUTION OF THE ORGANIZATION OF THE U. S. SHIPPING BOARD, EMERGENCY FLEET CORPORATION,[2] Charles Piez.

EMPLOYMENT OF LABOR,[3] Dudley R. Kennedy.

LABOR DILUTION AS A NATIONAL NECESSITY, Frederick A. Waldron.

INTENSIVE TRAINING,[2] C. R. Dooley.

[1] Published in MECHANICAL ENGINEERING, March 1919.

[2] Published in MECHANICAL ENGINEERING, January 1919.

[3] Published in THE JOURNAL, December 1918.

TEXTILE SESSION

PROPERTIES OF AIRPLANE FABRICS, E. D. Walen.
INDUSTRIAL POWER PROBLEMS, W. F. Uhl.
DAYLIGHT VS. SUNLIGHT IN SAWTOOTH ROOF CONSTRUCTION, W. S. Brown.
FACTORY STAIRS AND STAIRWAYS, G. L. H. Arnold.

GENERAL SESSION

THE WEIGHTS AND MEASURES OF LATIN AMERICA, Frederick A. Halsey.
EFFICIENCY AND DEMOCRACY, H. L. Gantt.

Thursday Evening

LECTURE AND ANNUAL REUNION

Lecture on RAILWAY ARTILLERY, with slides and motion pictures, by Colonel James B. Dillard, Engineering Division, Ordnance Department, U. S. A. Followed by the annual reunion and dance.

Friday Morning, December 6

SIMULTANEOUS PROFESSIONAL SESSIONS

POWER-PLANT SESSION

THE CONSERVATION OF HEAT LOSSES FROM PIPES AND BOILERS, Glen D. Bagley.

CHEMICAL AND PHYSICAL CONTROL OF BOILER OPERATION, E. A. Uehling.

THE COOLING LOSSES IN INTERNAL-COMBUSTION ENGINES AS AFFECTING DESIGN, C. A. Norman.

DISCUSSION OF CERTAIN PROBLEMS IN REGARD TO MARINE DIESEL OIL ENGINES, J. W. Anderson.

GENERAL SESSION

VALVES AND FITTINGS FOR HIGH HYDRAULIC PRESSURES, W. W. Gaylord.

THE RELATIVE CORROSION OF ALLOYS, R. B. Fehr.

THE RELATIVE CORROSION OF CAST-IRON, WROUGHT-IRON AND STEEL PIPE IN HOUSE-DRAINAGE SYSTEMS, W. P. Gerhard.

DETERMINATION OF STRESSES IN WIRE ROPE AS APPLIED TO MODERN ENGINEERING PROBLEMS, J. F. Howe.

MECHANICAL FEATURES OF THE VERTICAL-LIFT BRIDGE, H. P. Van Cleve.

Friday Evening

College reunions.

No. 1653

BROADER OPPORTUNITIES FOR THE ENGINEER[1]

PRESIDENTIAL ADDRESS, 1918

By Charles T. Main, Boston, Mass.
President of the Society

WE have probably witnessed the end of hostilities in the greatest conflict that the world has ever experienced. The people of this country, after some hesitation, undertook to assist in finishing the task which the Allies had begun at whatever cost or however long it might take.

It is now a time for great rejoicing, but the signing of the armistice is not the signing of the peace treaty. What kind of a peace we are to have will depend upon the wisdom with which the multitude of questions connected with the restoration and redistribution of territory and international relations are settled. The war will not be won satisfactorily unless the purposes for which it was fought, from our viewpoint, are assured.

At this time it may be well to recall why we have been at war.

President Wilson said, some time ago, "To make the world safe for democracy."

Lloyd George said, "We are fighting for a just and lasting peace."

Ex-President Taft said, "It is the struggle that is essential to liberty and Christian civilization."

Premier Clemenceau said, "Our victory and the victory of our allies means the liberation of civilization and liberty of human conscience."

Many other reasons have been and may be given why we were at war, but brought down to its final analysis, it is that this nation and other nations may live with the maximum of safety and with the greatest amount of liberty.

[1] Constituting the Report of the Council for 1918.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

Probably most of us have a vague knowledge of the many issues involved and an indefinite conception as to the effect of the war on the political, social and business conditions of the world, but we can surely predict that there will be a remolding of all these so that our country will be one of greater unity of purpose and desire with a more spiritual and less materialistic view of life and greater unselfishness in the service of our country and mankind.

WHAT HAS BEEN AND WHAT SHOULD BE OUR SHARE IN THIS GREAT MOVEMENT?

We, as engineers, have been endeavoring to do whatever particular work we are specially qualified to do directly for the military needs, and to conduct the affairs of the profession along lines of service to the nation directly or indirectly.

A brief survey of the work of the Society and its members during the past year is desirable as information to our own members and as a record.

It is impossible to separate some of the activities of the Society between purely war and purely technical work.

WAR ACTIVITIES OF THE SOCIETY

Some of the war activities of the Society have been described in a pamphlet which has been sent to each member, entitled "In the Service." In order to have this record complete in the Transactions of the Society, some of which was printed therein is here repeated.

Early in the war The American Society of Mechanical Engineers, in common with other engineering societies, tendered its services to the President of the United States. This offer was promptly accepted, and as the war has developed and the needs for service have grown, the Society has patriotically responded to the many calls which have come to it.

One of its earliest contributions was through representation on the Naval Consulting Board and its former Committee on Industrial Preparedness, which conducted the great industrial census whereby data were secured regarding all industrial plants in the United States doing an annual business in excess of $100,000. The Naval Consulting Board now acts as a board of inventions which passes upon the merits of new devices brought to the attention of the Government through various channels.

Another early contribution was in coöperation with the Military Engineering Committee, organized in New York for the purpose of arousing engineers to the necessity for preparedness and of instruct-

ing them in military tactics. Lectures were given in the Engineering Societies' building to over 3000 men and in the preparedness parade 10,000 engineers participated, and these successes were duplicated in other centers. Recruiting was actively taken up, for which purpose the Society's rooms were freely used, and the famous regiment, the Eleventh Railway Engineers, was organized.

The work of the National Research Council, organized at the request of President Wilson by the president of the National Academy of Sciences, is extremely important, dealing with problems such as submarine detection, nitrate production, gas warfare, etc. One of its committees is the Committee on Engineering, on which the Society is officially represented. THE JOURNAL of The American Society of Mechanical Engineers is also supplying to the Technical Information Bureau of the Research Council a regular service of engineering data from the engineering periodicals of the world.

During its first year the National Research Council was supported by the Engineering Foundation, the initial gift for which was made by a past-president and honorary member of this Society, who has recently made another generous donation to this fund.

As an active member of the Engineering Section of the Advisory Commission of the Council of National Defense, the Society has participated in several meetings which have led to definite and constructive assistance in the manufacture of munitions and in foreseeing the needs of the Government.

One of the most successful undertakings of the Society has been that of its Engineering Service Committee in classifying the membership and furnishing specialists for the numerous demands of the Government and the industries generally. A questionnaire to the membership brought in over 6000 replies, all of which have been collated and indexed in the most thorough manner.

It has supplied the names of more than 6000 engineers and engineering assistants for a wide variety of positions to the many departments and divisions of the United States Government in connection with the war.

This is the most important single bureau in the United States for the furnishing of technical men.

The last three conventions of the Society, held at Cincinnati, New York and Worcester, have been war conventions at which there were constructive programs devoted to great problems of the war.

In the matter of fuel conservation the Society has been very active through its membership on the Fuel Conservation Committee

of the Engineering Council, in coöperating with the Fuel Administration at Washington, and by service of its members on Commissions in different states. Lists of its members who are fuel experts have been supplied to the Government and at the Worcester Meeting a Symposium on Fuel Economy was held, to which contributions were made by over sixty experts from all sections of the country, and this matter has since been published in pamphlet form.

Action with respect to munitions and gages passed at the Society's meeting in Cincinnati resulted in a conference at Washington at which the heads of the Army, Navy and other Departments were present and further action was taken which resulted in having certification of all gages at one place, thus tending to insure uniformity of product. Later it was decided this would be undertaken by the Bureau of Standards in Washington with branches at various industrial centers. These have been established at the Engineering Societies Building in New York, at Cleveland, and at other centers throughout the Union.

An important development was the organization of the Engineering Council to provide coöperation between engineering societies in matters of common interest, particularly in relation to the public. The organization meeting was held in the rooms of The American Society of Mechanical Engineers and the then President of the Society was the first President of the Council. War activities are being conducted by several committees, including the American Engineering Service Committee, the Fuel Conservation Committee, and the War Committee of Technical Societies, the latter for stimulating inventions among engineers in weapons and apparatus for war.

One of the most recent activities of the Society is in connection with the readjustment of industries for war work, for which purpose a committee has been appointed, with representatives in different parts of the country, selected through the Local Sections of the Society.

The subject was first proposed at a meeting of the New York Local Section on Non-Essential Industries held last February. As a result a committee was appointed by the Council to investigate the matter, which recommended the creation by the Society of a bureau or clearing house to act between the Government and the manufacturers. This involved the establishment of a regional system for surveying the industries of the country in coördination with the Resources and Conversion Section of the War Industries Board, and a Central Committee of three, who will act in conjunction with the regional com-

mittees as a clearing house for problems, and members who have such problems will receive assistance, if they so desire.

Utilizing our Local Sections organization, your President has appointed 20 members of the Society to act as its representative on each of the Regional Committees of the Resources and Conversion Section of the War Industries Board, and a central committee of three in New York.

As much work has not been accomplished as was expected, but it has not been through lack of effort of your representatives.

The Society was invited to send delegates to the Joint Conference in London on Air Craft Standardization in London. We sent as our delegates Mr. James Hartness, Past-President of the Society, with Prof. W. F. Durand as an associate representative.

These delegates were also empowered to take up with the British Engineering Standards Committee the standardization of screw threads.

Information was received that a Belgian Mission was to be sent to the United States to study methods of scientific management in this country.

A committee of the Society met the mission on its arrival, placed the resources of the Society at its disposal, arranged the itinerary of the mission, and a bibliography on industrial management was prepared in our library.

The courage and vision of these men in looking forward to a reconstructed Belgium is inspiring. We should individually and as a Society render them all the assistance possible. It may be that there and in other countries we may be able to render great assistance in problems of reconstruction.

Letters were received from Henry R. Towne, Past-President of the Society, and from the National Council of Industrial Defense, covering proposed legislation whereby "anti-efficiency" riders were attached to appropriation bills for the support of the military establishment, which legislation would exclude from all Government work the methods of study, planning and compensation for increased efficiency.

Engineering Council, to which this Society referred the matter, sent resolutions to Congress, protesting against such legislation.

The A.S.M.E. Council voted that the Council records its hearty approval of any action taken by the Engineering Council in this matter, tending to prevent such legislation.

COLLECTIVE AND INDIVIDUAL SERVICE OF THE MEMBERSHIP

While the Society as an organization has made important contributions to the prosecution of the war, this work is only a token of what its members individually have contributed, in common with other engineers throughout the country. Its membership is represented in France on the Western Front, in the construction of water and sewage works, and in the great French arsenal for the repair of our equipment abroad. It has rendered effective aid in the organization of the construction division of the army and of the Ordnance Department and Shipping Board; in routing merchant ships; in promoting motor transportation; in the classification of personnel for the army; in emergency technical war training, and in the instruction of soldiers in handling guns and ammunition. Its members are to be found in every department of the Government where expert engineering knowledge is required.

Two members of the Council of the Society are in uniform in France and a third, as a distinct war service, is in charge of one of the largest shipbuilding yards.

The Society's service flag bears over 1400 stars and noteworthy also is the scroll of honor of the civilian members engaged in producing the supplies that the blows struck by those at the front may be telling and effective. These members have helped to bring about quantity production of rifles and machine guns, have engaged in the design and construction of aircraft and the motors and instruments required for their equipment, have engaged in the construction of artillery, gun carriages, tractors, army trucks, tanks, torpedo-boat chasers; and in the great shipbuilding plants, in both Government and private yards, members of the Society hold some of the most important positions.

SOCIETY AND TECHNICAL WORK

In addition to and in parallel with the war work, marked progress has been made in the internal affairs and in the technical work of the Society, always with the intent to render definite service and at the same time perfecting and coördinating work already undertaken.

At the time the Society became a joint owner and occupant of the Engineering Societies Building, the Society, in order to accept this gift, obligated itself to the extent of some $80,000.

During those early days, it seemed that it required about all the income that the Society received to pay what was deemed to be the necessary expenses of the work of its various committees, and until a

proposition was made for issuing certificates of indebtedness to the amount of $80,000, no definite plan for payment of the debt had been formulated. A happy provision in the issuance of these certificates was that they should be paid out of initiation fee of new members joining the Society. The healthy growth of the Society during the last ten years has been such that not only have these certificates been retired, but a substantial surplus has been created.

As soon as our country was brought into the war, and the members of this Society took their places in the ranks, it was at once apparent that the least the Society could do in showing its appreciation of the loyal sacrifice made by these members was to offer that the dues of such members who have entered the military service of the Government and upon request of the member, be remitted for the period of the war. It is possible that the Society may be asked to remit during the coming year about $10,000 on this ground; and although the Society is glad to do this, it means that some sacrifice must be made by the committees by the reduction of the amount which they had hoped would be available for their work during the coming year.

Under the wise administration of the Finance Committee, the Society for some years past has prepared a budget which provided for an expenditure of not more than 90 per cent of the expected income. Under the operation of this provision, the Society's net reserve has been built so that we have at present a cash reserve of about one hundred thousand dollars. The Society in harmony with its stated purpose to be of as great use to the country in this emergency as possible, has subscribed to each of the three previous loans $10,000, and $15,000 to the fourth loan, thus making $45,000 of Government bonds which the Society has taken.

These investments are in addition to the $56,000 invested in bonds in trust funds.

In this connection it is proper to state that the Society's real estate holdings represent an equity of one-fourth of $2,500,000 in the structural value of the Engineering Societies Building and land, all of which is free and clear.

The estimated income for the current year from all sources is $270,000. It is proposed that the total expenditure for the year will be $245,000. Of this, $235,000, or about 87 per cent will be taken from income, and $10,000 will be taken from the surplus.

On account of the unsettled financial conditions of the world, the conservative appropriation this year is made of only 87 per cent of the Society's prospective income. If, later in the next year, circum-

stances warrant increased appropriations to the Committees, the Council will probably deem it wise to see that a greater percentage of the Society's income is expended for the benefit of the membership.

With, however, the increasing scope of the Society's undertakings, there must be the greater provision for certainty of performance under any and all circumstances, even including war. Consequently, the accumulation of a surplus, and its continuation, is an obligation on the part of the Council.

The headquarters on the eleventh floor of the Engineering Societies Building have been the home of the Society, and have been under the watchful care of an efficient house committee. Not only has it been the desire of this committee to make the rooms attractive to the casual observer, but an endeavor has been made to give the rooms a homelike atmosphere so that the member would feel free to make the rooms his headquarters any time he should be in the city and should have opportunity for writing, reading, social appointments, the receipt of mail, and any other facility that the Society should so be able to furnish.

Under the conditions occasioned by the rapid increase of the activities of the Society and the necessary larger executive staff, it became necessary to remove some of the partitions in that portion used for the business of the Society, thus making a more up-to-date office for handling the Society's business.

The Society has extended a welcome uniformly to a large number of committees and organizations and the invitations have been frequently accepted. Carrying out this policy, the Council has donated for continuous use, for the period of the war, the Council and Reception Rooms to the War Department for its Committee on Education and Special Training.

The sections committee was authorized as a special committee of the Council to report to the Council a procedure whereby, by requirement, the Nominating Committee be regularly chosen through the medium of sectional groups of the Society, instead of being appointed as at present by the President.

A report was submitted by the special committee, the principle of which was accepted with some modifications by the Council, and the Committee on Constitution and By-Laws was requested to prepare the necessary changes in the constitution and by-laws to carry out the plan. This committee was later requested to report the following amendment to the June meeting, viz., to change "A Nominating Committee appointed by the President" to read "A

Nominating Committee to be elected by the voting membership as the By-laws shall provide."

This is one of the moves toward a wider control of the Society's affairs by the membership.

A Committee on Administration, of which the late Chairman of the Finance Committee, Mr. R. M. Dixon, was chairman, was appointed principally to investigate the internal affairs and the conduct of the office of the Society, and to give to the office the benefit of their wide business experience. In order that the larger financial undertakings of the Society might be conducted in the best manner, Mr. George M. Forrest of the Finance Committee was designated as the representative of the Committee, and he has been most faithful and many helpful suggestions were made and put into effect.

In accordance with the amendment to the Constitution now in force, the Finance, Meetings, Publication, Local Sections, Constitution and By-Laws Committees are now constituted, the Standing Committee of Administration having a seat in the Council of the Society without vote.

In addition the Council regularly invites the chairman of the Committee on Standardization to sit with the Council.

The Employment Bulletin is one of the most important personal activities of the Secretary. It seems to meet one of the phases of life that is of great value to the membership. Consequently, the attention to this particular activity should be proportionately increased.

Plans are being developed whereby the facilities of all the Founder Societies will be coördinated.

The Publication Committee has for years been aware of the deficiency in all existing indexes of current literature and has been awaiting the time when the finances of the Society would permit, for the further benefit of our membership, the inclusion in our publications of an adequate résumé of the vast and most complete file of technical papers, which we regularly take in the combined libraries of the Societies.

An additional appropriation has been approved for enlarging the Society's Journal by adding an Index of Current Engineering Literature.

Other progressive plans are under way for improving THE JOURNAL. It has been suggested that it might be published weekly instead of monthly.

The Boiler Code Committee has done a vast amount of work on the revision of the code to cover all questions of doubt as to the inter-

pretation of the code and the proposed final revisions have been printed in THE JOURNAL. The code is now ready for printing in the new edition.

Possibly no committee has brought more prestige to the Society than the Boiler Code Committee. The members have been most unselfish in their efforts and have devoted days and weeks of intense labor and much of their own money to this work.

The President desires to acknowledge the indebtedness and gratitude of the Society to this Committee.

As a reward to the Committee, it has the satisfaction of seeing the code adopted by five states and seven municipalities.

The National Research Council made a request for the appointment of a representative of the Society to sit with the Executive Committee of the Engineering Division. Mr. John R. Freeman, Past-President, has been appointed as our representative.

Research Committees engaged on purely technical work not connected with the war have made progress and several have reported and their reports been received.

Other committees have done excellent work and made exhaustive reports, the report of the Committee on Tolerances in Screw-Thread Fits being a remarkable piece of work.

Reports have been made of tentative drafts of safety codes by the Sub-Committee on Protection of Industrial Workers.

With respect to the Research Committee, the Council has enthusiastically placed in the budget $2000 for the Committee. In previous years this has been only $500. With the financial growth of the Society, and its ability, on the one hand, and responsibility, on the other, to furnish greater service to the profession and to the public, increasing attention should be given to research. There is an unusual opportunity for the coöperation of the Research Committee with the Publication, Meetings and Sections Committees. Research can be inspired in the sections, results read at local and general meetings, and published in THE JOURNAL, investigations of the progress of certain arts made and reported for the benefit of the whole people.

In addition to the coöperation through the Society's representation on the Executive Committee of the Engineering Division of the National Research Council, the Research Committee of the Society has placed at the disposal of the Engineering Foundation its data on the research laboratories in the industries, colleges and commercial laboratories in the United States.

A commission has been created by the United States Government

for the Standardization of Screw Threads, H. R. Bill 10,852. It is mentioned in the bill that two of the members of the commission shall be members of The American Society of Mechanical Engineers. Mr. James Hartness, Past-President, and Mr. F. O. Wells, member-elect of the Council, have been appointed as our representatives.

A committee has been appointed to coöperate with the British Engineering Standards Committee on the Standardization of Milling Cutters and Other Small Tools.

An informal corresponding committee has been authorized to correspond with the British committee, the object of which is to help standardization work in an informal manner, especially from an educational point of view.

The Power Test Code Committee has been reorganized with subcommittees for each particular code which is to be prepared.

Some progress has been made, the code for water-wheel tests has been rewritten and is now ready for resubmission to the committees.

A BROADER VISION

With this review of what the men in our profession are doing in connection with the war and the collateral problems, also having in view the quick expansion and development of the work along comparatively narrow and restricted lines into circles of almost unlimited possibilities, we have seen how we can and must free ourselves from our former provincial attitude into one of universal outlook.

If this can be accomplished at this particular time and for this particular occasion, why should we not now and in the future exert our influence and direct our energies toward matters of broader interest?

As a class engineers have been extremely modest in their relations with business and public affairs. This has been a natural condition largely due to the education and training which they have received. The education has been along rather narrow and restricted lines of scientific work, leaving out almost entirely the broader studies of literature, common law, economics, business methods and the humanities. After graduation there is usually not much opportunity for broadening out, for it is necessary for a man, if he expects to keep abreast with the development of his profession, to spend nearly all of his surplus energy in reading and studying along the very lines which he followed in school.

Notwithstanding this, it is wise to carry along a course of reading on broadening subjects and to have an interest in affairs which

are wholly outside the scientific line of study, and to be identified with engineering and scientific societies in order to get the broadest outlook of life possible. It is for this reason, in order to get a broader aspect of life and acquire a taste for wider reading and study, that it is of advantage for a young man who is to follow some scientific pursuit to take an academic course before he takes his scientific course.

I realize the impracticability for many men to spend so much time at considerable expense in preparation for their life work, but it is almost essential that a man should very early in his career acquire some knowledge of business principles and should endeavor to broaden himself so as to be able to fill with fair satisfaction the position that properly belongs to him in his profession and in the world.

It should be the aim of the engineer to render the best possible service considered in a broad sense. It should be based on facts and not theories or suppositions, and upon scientific laws, which if properly applied will give satisfactory results. Nothing should be taken for granted, and the work or statements of others should be carefully checked before being adopted.

The success of a man will depend upon his ability to produce results in an expeditious manner, which shall be accurate, and in which good judgment has been used, so that the finished product, if it be a physical structure, will be adapted to the use to which it is to be put and shall have been accomplished at a reasonable expenditure. If it be a plan for action it shall be clear and concise and adaptable to the purpose for which it is intended.

He should be able to understand men and to know them. He should be willing to share his knowledge with his fellow-engineers, and inasmuch as he will do this through the Society, or other similar means, his interests and outlook will broaden and the return to him will be multiplied. Integrity and perseverance in work and business and fairness and justice to all will in the long run count for more than brilliancy in attainments. Withal he must have a good stock of imagination and judgment, which is sometimes called "horse sense" in the application of fundamental principles to every day problems.

The true success of a man is not measured by the accumulation of money, but by the success of accomplishment of work which adds something to the general good for mankind and for the advancement of the profession.

In his annual address President Hollis said:

> In the changes that are coming, the engineer can no longer dwell within his technical shell, and he must prepare himself to become a citizen of the world, upon whose shoulders great economic and social burdens are placed.

And Professor Kimball has said:

> If we have not at this moment a clear vision of whither we are tending, now is the time of all times to take stock of ourselves and to redirect our course, whether this course is in conformity with time-honored definitions or not. Change is not necessarily synonynous with progress, but there is no progress without change. No one can doubt that the scientist and the engineer are to be the most important industrial figures of the near future. If we are faithful to our duties we shall be of greater importance politically and socially, but to accomplish this we must broaden our vision and get about our business, which is the industrial organization of our country.

Let us then bestir ourselves and show a greater interest and a broader vision of the opportunities which now lie before us and which will increase in number and importance in the near future.

WITHIN OUR OWN SOCIETY

There has been a feeling among many of our members that the affairs of the Society are run by a selected few with headquarters in New York. During my service of three years on the Council, it has been the desire of every member to administer the affairs of the Society for the benefit of all the members in every locality and this spirit has been dominant above all others, and the desire to increase the local sections and to have them assume greater responsibilities has always been evident. It is only in appearance that the faithful members, assigned to the important and necessary duties of the executive head in every organization, if it is to be effective, are running the business. The organization must be so constituted and located as to take quick action and it is far from the desire of the governing board to conduct the affairs of the Society for one particular locality or interest.

In order to meet all criticisms and to develop plans for future procedure, the Council has authorized the appointment of a Committee on Aims and Organization, which is made up of one member from each Local Section and seven members at large, whose duties it shall be to consider the whole structure of the Society and its activities with great care and report a line of action based on broader conceptions of our duties and aims and how best to accomplish them.

In anticipation of the work of the committee, there may be

mentioned some details of operation in the minor workings of the Society which might be broadened to advantage.

A plan might be developed for increasing the financial resources of the Society by contributions or legacies to a fund, the income of which could be devoted to research work and for prizes and premiums to the younger members for good work and for any other meritorious object which might present itself.

A plan should be developed which will make a working connection between the general meetings and the local meetings.

The coöperation between the Publication and the Local Sections Committees can be greatly developed if the individual members will see the great opportunity which these committees have already provided in the equal status of papers read before local and general meetings of the Society. The members can further help the Publication Committee in conjunction with the Meetings Committee by an earlier announcement of prospective papers, so that a general program for the ensuing year can be prepared during the summer and be submitted to all of the local sections and coöperation solicited in carrying such a program to completion.

During recent years the increased responsibility placed upon young men has increased the difficulties of the Membership Committee in the proper grading of applicants for membership. It may be that the Committee on Aims and Organization could well give consideration to this matter.

As already indicated, another profitable investigation which the Society can undertake is a still closer relation between the Research Committee and our other committees, including the Engineering Foundation, with the industries and with the scientific schools having facilities for research work. It has been suggested that the Society act as a clearing house between the research facilities of the universities and the research requirements of the industries.

Most of the broader aspects within the Society are in line of extending the usefulness of any one activity through the medium of coördinating it with some other activity. The whole organization is capable of being rounded out and planned so as to produce the maximum of team work.

IN THE PROFESSION IN GENERAL

We are living in a period of profound importance to the whole world. The social and political conditions and the ideals of some and perhaps nearly all the nations are in a state of flux. To a large

extent this may be said of our own country. This state of uncertainty and uneasiness has overtaken many men in our own profession and it seems, therefore, necessary for us to consider with great care if it will not be necessary in the near future to readjust ourselves to the new conditions.

There is a tendency to form new organizations to accomplish new objects, or with the hope of doing some things that the present organizations are doing in a better way. This is unfortunate, as it is unwise and inefficient to have so many agencies endeavoring to accomplish the same result. Consolidation rather than segregation, up to proper limits, is desirable.

In local communities some plan should be arranged, which would vary in different places, for the local organizations to combine on matters of common interest. The plan, however, is of less importance than the action itself. If the local societies and members of the same are active in service to the profession and to the community, a plan will be evolved by which these interests and activities can be made effective.

ORGANIZATION

It was probably for this reason that the American Society of Civil Engineers, on June 18, 1918, created a Committee on Development and adopted resolutions creating the committee, a portion of which reads as follows:

> The development and application of the sciences in recent decades have caused profound changes in the social and industrial relationships of all peoples.
>
> Sociological and economic conditions are in a state of flux and are leading to new alinements of the elements of society.
>
> These new conditions are affecting deeply the profession of engineering in its services to society, in its varied relationships to communities and nations, and in its internal organization.
>
> A broad survey of the functions and purposes of the American Society of Civil Engineers is needed in order that an intelligent and effective readjustment may be accomplished so that the Society may take its proper place in the larger sphere of influence and usefulness now opening to the profession.
>
> Resolved, that a Committee be created to report on the purposes, field of work, scope of activity and usefulness, organization, and methods of work of the American Society of Civil Engineers, and to make recommendations concerning these matters.

The purpose and scope of the work of the committee is thus in part defined:

> It is intended that the Committee on Development shall make a survey of the fields of usefulness which are or should be open to the Society, consider what functions may properly be assumed by the Society, define its purposes, formulate

policies and methods of work to be recommended, and consider the needs in organization and constitution. This means taking stock and making plans. The resolutions contemplate an examination of present-day conditions and an outlook into the future. They involve considering the changing social and industrial relations of the times and the opportunities and responsibilities which devolve upon the Society and its membership. The relations of the Society to other societies and to the profession generally are also included. The outcome of the work of the Committee may be modifications in the activities, functions, and methods of work, or in the emphasis in these matters, and possibly the addition of new ones.

Similar committees have been created by the American Institute of Electrical Engineers, and is proposed for the American Institute of Mining Engineers, and our own Society. It is proposed that the various committees coöperate on subjects of common interest.

It is also suggested that it may be desirable to confer with representatives of local engineering societies throughout the country concerning the relations of such societies with the national societies.

The results of this work should be of great benefit to the whole profession in increasing solidarity, diminishing duplication of effort, more effective results in matters of common interest, a more representative opinion on subjects of general interest to the profession and public, the creation of a better feeling of fellowship and harmony and a much greater ability to assist in the inevitable evolution of industrial and social conditions which are soon to follow.

The advantages of unified command and action are most clearly demonstrated by the results obtained by the allied armies under the supreme command of General Foch.

The Engineering Council is a step in the direction of coördinating the work which is of common interest to the profession. It has done much good work, but has not yet reached the maximum of its usefulness.

CONSOLIDATION OF TECHNICAL SOCIETIES

In the Monthly Bulletin of the American Institute of Mining Engineers, March, 1918, there appeared the following:

The vision dwells in the minds of many that ultimately these four great societies, lightening the emphasis they place upon their differences, may see the time when, for the solidarity of the profession, for their best interests, as well as for increase of their influence on the country at large, they may become one great national association of engineers. With the gain in power and prestige inevitably following such an aggregation, freedom for individual development may be achieved through divisions along the lines of technical interests, which might either follow the present four grand divisions or be more minutely subdivided.

An organization of this sort could and probably would be more strictly professional than any of the four have been heretofore, and through the prestige and power of its numbers could establish standards of ethical conduct for its members, violation of which would bring grave consequence.

This great vision is worthy of the most careful consideration and might be carried with safety to a point where the national societies would be gathered in under one executive head, without any one losing any vital portion of its individuality.

This would be a great step in advance and perhaps as far as we should go for some time to come.

STANDARDIZATION

There is now opening up to the profession the most promising opportunity of furthering the work of national and international standardization. It is the beginning of a real great international movement for standardization.

All of our own standards committees are working under the general direction of the Standardization Committee, the sole duty of which committee is to see that the work of the various committees shall be in harmony with the general scheme, but not to prepare standards for any particular purpose.

The American Engineering Standards Committee has been created for the purpose of harmonizing the standards of the various branches of the profession, and it is about ready to function.

Upon invitation of the British Engineering Standards Association, this Society is acting as an informal correspondence committee in the United States.

NATIONAL DEVELOPMENTS IN WHICH THE PROFESSION CAN BE BE OF ASSISTANCE AND GUIDANCE

Although the military conditions with the Allies in Europe are satisfactory, there is a vast amount of work yet to be done in clearing up the whole situation and our efforts should not be diminished until a satisfactory ending is reached.

It is now time to give careful consideration to the readjustment after the war so that this country shall maintain its national and industrial integrity with due regard to our obligations to other countries. We were unprepared for war, which was a possibility, and we are unprepared for peace, which is a certainty.

The future will have problems and trials. The contests will not

be of battle but of industry. The conquests will not be of territory or thrones but of markets.

Plans have been under consideration for some time in England, France, and Germany for regaining the commerce lost during the war.

Upon our ability to resume our normal lines will depend to a large degree our prosperity at home and trade expansion abroad.

We were unprepared for war and it has been a stupendous task to readjust our industries to a war basis. It will be no easy task to readjust ourselves for peace. In this readjustment our vision must extend beyond the state and nation out into the broad world.

"With courage we must face the future, confident that with a better understanding of our local and national problems, and with a closer and more systematic coöperation between the governing authorities and business institutions, continuing progress will be assured. These are not times for jealousies, prejudices and selfishness, but with a largeness of heart and bigness of vision we must unite in a common effort to help America achieve its manifest destiny."

Bills have already been presented to Congress which contemplate the creation of a Federal Commission on Reconstruction, the duties of which are far reaching. The Commission is to investigate and recommend to Congress what additional legislation or changes in legislation are desirable.

Under the Weeks Bill the subjects are summarized as follows:

1 Problems affecting labor.
2 Problems affecting capital and credit.
3 Problems affecting public utilities.
4 Problems resulting from the demobilization of our industrial and military war resources.
5 Problems affecting our foreign trade.
6 Problems affecting the continuance of existing industries and the establishment of new industries.
7 Problems relating to agriculture.
8 Problems affecting the adequate production and effective distribution of coal, gasoline, and other fuels.
9 Problems relating to shipping, including shipyards, and especially in regard to the sale, continuance of ownership, or leasing of both yards and ships.
10 Housing conditions and the disposition of houses constructed by the Government during the war.
11 War legislation now on the statute-books, with reference to its repeal, extension, or amendment.

12 And in general all matters necessarily arising during the change from the activities of war to the pursuits of peace, including those that may be referred to it by the Senate or House of Representatives.

Under the Overman Bill the tasks named are as follows:

a The financing, regulation, control, and development of the merchant marine.

b The development, financing, expansion, and direction of foreign trade.

c The reorganization, financing, and readjustment of industries engaged in war work by way of reconverting them to normal production.

d Technical education and industrial research as a means of developing and strengthening industry.

e The redistribution and employment of labor in agricultural and industrial pursuits and the problems of labor growing out of demobilization.

f The supply, distribution, and availability of raw materials and foodstuffs.

g The conservation and development of national resources.

h Inland transportation by rail and water.

i The reorganization of government departments, bureaus, commissions or offices with a view to putting the Government on an economical and efficient peace basis.

k The consolidation of such acts and parts of acts of Congress which relate to the same subject-matter, but which now appear at various places in the statutes.

Nearly all of the problems suggested above are directly or indirectly engineering problems. The framing of laws would be greatly facilitated if the advice of the engineers were made available in furnishing many of the physical and technical facts upon which they should be based.

Nearly all of the problems of a municipality and largely of the state and nation are engineering in their nature and it should be the duty of all engineers to take an active interest in the conduct of public affairs in so far as the opportunity offers. It is always possible in the smaller way in the community and the opportunity will broaden if a man shows his ability and interest into fields of wider scope.

Our assistance will be needed now more than ever, for the tendency of the times is towards socialism and government ownership or control of all facilities which are used by the public. The arm of federal

authority is reaching further and further into our personal life and affairs. We are moving rapidly in the transfer of authority from hose who have a personal interest in its successful exercise to those twho have only political advantage to gain.

This Society, other societies and Engineering Council are already working on some of the problems. We are not concerned with all of them at present, but should be soon. We should begin to look upon all of them with a broader vision, and should take a more active and helpful attitude toward public affairs and industrial relations which we have heretofore considered beyond the scope of our work.

One of the reasons why we have not accomplished more during the war has been the difficulty of making a definite connection or association with the military operations of the Government. It has been suggested that some arrangement might be made between the Government and Engineering Council, by which all kinds of engineering and kindred problems could be submitted to the Council. It is also suggested that Engineering Council offer its services to every congressional committee having problems of an engineering nature to report upon. If it could be brought about that the engineers would be invited to assist, it would be a very satisfactory arrangement.

There will probably be many commissions established on which an engineer member would be of great assistance in transmitting to the other members such technical information as they would need to understand the fundamentals of the technical portion of the problem and in directing the line of effort for obtaining the technical data required.

Before we can make a successful connection, however, we must have enough knowledge of their problems and enough imagination to be able to suggest along what lines we can be of assistance.

While we are holding our convention, the National Council of the Chamber of Commerce of the United States is being held in Atlantic City, for the purpose of formulating plans for reconstruction of business.

READJUSTMENT OF LABOR AND TREATMENT OF EMPLOYEES

Probably the greatest problem before the nation is the redistribution and readjustment of labor. The following is quoted from a bulletin of the Chamber of Commerce of the United States with reference to "A New Service."

War conditions impose upon business and industry problems of great difficulty and unusualness, requiring united thought and action.

The conditions of shortage of labor, the great pressure of demand for products,

the shrinkage in the purchasing value of the wage, and the spread of democratic ideas have created the necessity for labor administration all along the line from the Government down to the small private manufacturers.

These developments have all come about so rapidly that their implications and necessary consequences have not been realized. The most far-sighted and intelligent opinion sees in these events the beginnings of revolutionary changes in industrial relations which will eventuate in a strong federal labor administration to control this vast machinery.

The employers have an unlimited opportunity at the very beginning to participate in this administration. The danger of failure is greatest from indifference and lack of understanding among employers, from an unwillingness or incapacity to learn coöperative in place of competitive methods.

The War Service Committees, under the direction of the Chamber, are working out adjustments called for by the War Industries Board as regards materials, fuel, and transportation. The Committee on Industrial Relations has undertaken similarly to join with the War Labor Administration in its task of procuring the maximum utilization of our labor resources.

To investigate all experiments and developments in industrial relations both in this country and abroad and to place before the membership the results of such research. To assist the constituency of the Chamber in bettering the relationship between employer and employee by making available the records of the best experience and practice concerning wage and hours adjustment; methods of handling grievances and discipline, industrial service (improving the working and living conditions of employees and their families, housing, medical service, recreation, insurance, accident prevention, etc.); dealing with labor organizations; utilizing mediation and arbitration in disputes; securing the coöperation of employees in raising standards of efficiency; improved methods of employment management, hiring, transfer and dismissal, fitting the men to the job.

The permanent results of the activities of this committee will be educational. If successful, it will have created in the minds of employers a rational attitude, supported by facts and information, concerning the relations between themselves and those whose interests they are administering. The wage earner is just as dependent upon the intelligent and successful administration of enterprise as is the business upon the loyal and efficient service of the employees. The war has given an impetus toward democratic methods of administration both in public and private enterprise. Industrial administration must adapt itself to those conditions and conform to the prevailing ideas of the time or find itself in antagonistic relationships with all interests with whom it must deal. The employer must conceive himself to be a trustee of the interests of all involved in his enterprise and see that these interests are properly represented, lest he be confronted with opposition handicapping all his efforts. These administrative difficulties are not wholly the product of war nor will they disappear at the close of the war; indeed, it is more likely the industrial problems will increase in complexity with the coming of peace.

These quotations have been made because they describe the problems and responsibilities which are ours.

This vast and wonderful industrial organization with which we are living and struggling, is the growth of the last century. Its growth

has been so rapid that neither the employer nor employee as a whole has been able to see with clear vision a just solution of the many problems of relationship one to the other. For this reason there have been misunderstandings and struggles of great intensity with the tendency of further separating the two parties, whose interests are largely in common. Protective organizations have been formed principally by the employees, whose object is primarily the betterment of the conditions of the working people. Just so long as these organizations representing the employer and employee are managed and conducted for the general welfare of the community as a whole, they may be of service to the country, but when their affairs are conducted in a manner prejudicial to the interests of the community, they should be curbed.

Organized labor has its plans for the present and after-the-war period, which from all indications are very far reaching. The industries may have some plans, but they are not much in evidence.

The real issue is whether the genius of American individual enterprise is to be free, with due regard for the opportunity and welfare of all the people. The responsibility of guiding the republic rests upon such thinking men and men of experience as are members of this Society.

Many of our members are now vitally interested as employees with these great relationship problems. Some of those who are now employees will later be advanced to the position of employer, and knowledge of these problems will better fit them for advancement. By treating this matter on a very broad basis far greater progress will be made toward the establishment of satisfactory conditions than by settling down into a condition of stubborness and refusing to look the facts in the face and endeavoring to operate under conditions which may be wholly in opposition to preconceived ideas of what is proper.

We had our labor problems before the war, they will be more complex after the war, on account of the readjustment which must take place. The bulk of the men who have gone into the service will return, many women have gone into the industries and into work heretofore done by men only, and in many instances they have surpassed all expectations. The policy to be followed by foreign countries to regain their lost or impaired commerce will have a bearing on our problems.

These and many other questions will tend to make this problem more complex.

It is hoped that as a result of this war there may be greater efficiency in industry, a better use of the productive potentialities of men and materials, more perfect business organizations, elimination of waste, the doing away with many non-essentials and extravagances, but no amount of organization, standardization and control will be of any consequence in increasing production, unless the workmen concerned will put forth the requisite effort, and unless labor stands for increased rather than decreased production, this country is on the way to industrial ruin.

As business men, employees and employers, we can individually bring influence to bear toward a fairly just and satisfactory treatment and solution of these problems, and as professional men, without prejudice, we should be qualified to discuss with impartiality these problems and act as arbiters in the settlement of many questions of doubt.

The real and great problem extends far beyond the adjustment after the war. It means the development of relationships which will enable all of our citizens to live and work together under conditions which will produce the maximum amount of happiness and contentment possible for years to come.

It is perhaps nothing more than a dream of De Constant, the realization of which is far in the future, but if we all think and work along lines which will lead up to its accomplishment, it will be approached as years go by.

"The spirit of domination will lose more and more its prestige, while a policy of justice and conciliation will impose itself as being the only one corresponding to the aspirations and progress of humanity." (De Constant's America and Her Problems.)

EDUCATION

Another one of the most important problems in which the Society could be of great assistance is education.

The Council of this Society has been acting upon the assumption that the war may last for several years and that it would be a calamity to withdraw from our colleges and scientific schools all of the raw material for immediate use in the field, unless the crisis becomes more acute than it has yet been, but that this material should be retained for training in order to supply the loss of men which will occur if the war should go on for some years and the increased need of men trained in the sciences and industries. It petitioned Congress to enact such legislation as would enable drafted men to be assigned to special study or work and not to be called into active service until

they have been fitted for the work which they can do best, unless it is absolutely necessary to have immediately a vast amount of man power in the field.

The resolutions called for "Maintaining unimpaired the engineering strength of the nation for the prosecution of military operations and for the support of the sustaining industries."

"It urges that schools of engineering as the principal sources of this training be regarded as closely allied in the material purpose with military and naval schools of the Nation."

Copies of the resolutions were sent to the Secretary of War and the Provost Marshal.

A committee was appointed to ascertain the availability of technical schools and laboratories and what other opportunities there may be for industrial training.

Resolutions were passed and sent to the Secretary of War, protesting against the diversion of engineering schools from their primary function of advanced technical education, because of the persistent pressure for a training of technicians for the war.

As a result of these resolutions the Secretary of War appointed a Committee on Education and Special Training. Another result was the nationalization of scientific schools and colleges.

Committees of various kinds have been created for directing the work of special education and training for the war, but very little actual work has been done with reference to education after the war.

Bills have been passed in Congress making substantial sums available for vocational education upon joint action of the states with an equal appropriation of the allotment to the state.

If the manufacturers of the country desire to utilize this fund, it is up to them to secure the assistance of the state; otherwise the fund or that apportionment for the state not taking advantage of the opportunity will be turned back into the Treasury.

The Federal Board for Vocational Education has undertaken the work of reëducating disabled soldiers and sailors. It has made the following statement:

> In dealing with the disabled man, the Board expects to treat him throughout as a civilian needing advice and assistance, to approve his choice of occupation, unless, after careful investigation, sound opinion shows it to be in the end not advisable to train him to meet the needs of the occupation he has selected, to urge him to make the most of his opportunity to overcome his handicap by taking thorough-going instructions, to help him to secure desirable permanent employment, and to keep in close touch with him after he goes to work.
>
> The manufacturer should be greatly interested in this work of rehabilitation

and should aid the Board in every possible way. The War Department expects to train a large number before the year is out.

These reëducated men, made proficient in some trade or operation suited to their remaining capabilities, are going to constitute the most available source of skilled labor for some time to come. They will probably be the most dependable labor in the inevitable period of unrest and readjustment after the demobilization of the armies, when the country is settling back into a normal condition again. These reëducated men will form a core around which the newer labor can center. The manufacturer who has the foresight to make liberal use of these retrained men is going to have an immeasurable advantage over his competitor who trusts to luck to get the help he needs out of the disbanding armies.

Very little, other than that already described, has been done with reference to education after the war. This work should be begun immediately. Plans should be made for reconverting the scientific schools and colleges back to their peace program.

Many of our members are engaged in manufacturing and many in teaching. We have committees on Industrial and Vocational Training. There should be coöperation between the industrial plants and the schools. We can be of great assistance in the practical redevelopment of the educational systems and in the relationship between the schools and the industries, in the rehabilitation of crippled soldiers and industrial workers and the teaching of the blind, in an endeavor that every man shall have an opportunity to earn a living in a way that will carry with it some degree of happiness.

A portion of a recent editorial in London *Engineering* reads as follows:

Education in its broader sense should have as its main object the training of the mind towards the achievement of greater happiness and this can only be got by developing the thinking faculty so that a better perspective of life can be obtained. Thereon rests the hope for greater amity between employer and worker and a higher realization of the duties of citizenship.

The recent report by Dr. Charles R. Mann, entitled "A Study of Engineering Education," prepared for the joint committee on engineering education of the National Engineering Societies (Bulletin No. 11 of the Carnegie Foundation for the Advancement of Teaching), should be read by everyone who is interested in engineering education.

The report should be of great assistance in the reorganization period. I am in accord with many of the recommendations and conclusions, particularly those mentioned in the introduction by the Joint Committee on Engineering Education, which reads as follows:

Other significant characteristics of the report are found in the discussions of the general failure to recognize such factors as "values and cost," the importance of teaching technical subjects so as to develop character, the necessity for laboratory and industrial training throughout the courses, and the use of good English.

Another point emphasized, and one of deep importance, is that of the reorganization of curricula which are commonly acknowledged to be much congested, and which it is stated will continue, "as long as departments are allowed to act as sole arbiters of the content of the courses." Plans are offered for developing particular types of curricula suited to the environment of each school.

Emphasis is also given to the necessity for a broader training in the fundamentals of science as an equipment for all engineers and forming a sort of "common core" to every curriculum. With this broad training in the first and second years the student is expected to develop some natural leaning toward a specialty, and then will follow vocational guidance in the later stages of his education.

The scale for measuring the success or failure to provide proper training for engineers has been created by the practicing engineers. That scale is the improvement of character, resourcefulness, judgment, efficiency, understanding of men, and last of all, technique, as shown by students.

With the conversion of the schools and colleges to war work, intensive study became necessary. Everything except the essentials was eliminated, with more hours of work per year.

It would be a good thing if in the reorganization period much of the specialization work can be eliminated and thus a shorter time be required for college work for the bulk of the students, and if a greater portion of the year could be devoted to work, thus using the educational plants to a higher degree of efficiency, that is, with a higher load curve.

In educational, as well as in other lines of endeavor, if we have not learned a lesson of conservation of time and effort, we shall have missed some of the benefits which it is hoped will be derived from the war.

CONSERVATION

Next in order of importance to labor in the industries is the ability to procure raw materials in sufficient quantities and at reasonable prices. I will not dwell upon this subject, but will pass to the question of power, with which we are more closely identified, and which affects directly the bulk of our people.

Many of our members have been assisting in the conservation of fuel by serving on committees or individually in attempting to assist the various fuel administrators in the country, or on committees or commissions established for the proper development and utilization of our water resources.

Considerable savings in fuel have been effected recently by more careful attention to the burning of fuel and the use of steam in prime movers, but much more has been saved in simple commonplace and common-sense ways of preventing the waste of heat and power after it has been delivered from the boiler and engine rooms to the various rooms and departments about the plant.

An example of the sort of work which the engineers can accomplish in fuel conservation is that done by the Advisory Engineering Committee to the Fuel Administrator of Massachusetts, all of the members of which, with one exception, are members of this Society, in the assisting in the establishment in every plant and building using steam for heating and power, of a "Fuel and Power Committee" within its own organization, whose duties are, —

1 To see that fuel is burned economically and to prevent waste of steam and power.

2 To initiate and carry on a campaign of education among fuel and power users.

3 To distribute among users, engineers and firemen an outline of the items of loss, and to supply information for the purpose of saving fuel and power.

4 To assist local fuel committees in enforcing economies in wasteful plants.

5 To enlist the services of engineers in carrying out this program.

Similar work has been done by other committees in many states.

During this work, however, we have been endeavoring to get the best results with the existing facilities. We should now be studying the vaster problems which are to be undertaken in the future for the conservation of our natural resources.

The generation and transmission of energy by electricity has changed the conditions so radically in the last few years as to require the most careful study of the proper place and manner of the production of power for all purposes.

The problem of power supply is very intimately connected with the railroad and transportation problems and a study of one involves the study of both.

There have been very serious delays in the transportation of materials and supplies, and one of the principal reasons for coal shortage last winter was a lack of sufficient transportation facilities. It is stated that about one-quarter of all the coal used and transported is for the use of the railroads, and another large portion is required for manufacturing, lighting and power. Some of this

necessarily must be used at the plants for heating and manufacturing purposes.

Much of this traffic could be eliminated by the establishment of large steam-generating plants located as near the coal mines as conditions will permit, and on tidewater, where coal and oil could be brought in by vessels, by the development of hydroelectric powers, which are within reasonable distance of the market, and by the electrification of the railroads, with great trunk connecting and transmission lines. Incidentally with the further development of hydroelectric power is the saving in labor required for the mining, transportation and burning of coal.

Savings can be made by more careful study and use of the waste heat of furnaces in the form of gas for the production of power, and from steam turbines and engines by the use of steam and warm water for heating and manufacturing purposes.

Further conservation of power and fuel can be made by interconnecting transmission line between the hydroelectric companies so that the greatest possible use could be made under the varying conditions of flow of the steam at the different developments.

Still further saving of fuel can be made by the redevelopment of many of the older water-power plants, which contain inefficient wheels in efficient settings, and it may be possible in many cases to increase the capacity of the plant so as to use all of the water for a longer period of the year and waste water for a shorter period.

The conservation of flood waters, now wasting, by the construction of storage reservoirs, is receiving greater consideration. Special commissions have been appointed in some states for the study of this question, but as yet no great progress has been made so far as reservoirs for power are concerned. Most of the reservoirs for power already constructed have been built by private interests and by agreements among parties deriving benefit from such reservoirs.

The four chief reasons why this sort of development has not proceeded more rapidly are that the development expense and yearly charges of many would be so great that the returns would be insufficient to offset them and show a fair return on the investment, the inability of parties at interest to agree on some working plan for sharing the expense, that legislation has been of a discouraging nature, and because in the past all values have been measured in dollars and cents, as applied to the cost of power with not much consideration to conservation or the uses to which the power was put.

The expense of such large developments at the mouth of the mines and at tide water, and of the development of some of the hydroelectric powers, may be too great for private interests to undertake. The uncertainties and restrictions imposed have been such as to prevent the development of some of the possible water powers. More liberal legislation is needed to encourage these undertakings in many of which the margin of profit is small and doubtful. Congress has now under consideration a water-power bill which it is hoped will encourage developments.

From now on we should consider the value of development with a broader conception of not only the net comparative cost of power, as produced by one means or another, but also in connection with the desirability of having another instrument by which the full production is assured, the value of the product being far greater in most cases than the cost of power, and with the desire to conserve our natural resources, and with a view in times of shortage, of assisting in the general stabilization of business.

It is not conceivable, however, that the business men will be willing to make expenditures for anything that will not improve their own property or conditions, and any excess expenditure required for conservation for the benefit of the general public must be met from the treasury of the public. It is conceivable and proper, however, that the individual should take a broader view of the benefits to be derived from expeditures for his own benefit.

The basis for valuations of all properties or undertakings while subject to discussion and variation of opinion, was fairly recognized three or four years ago. Estimates of initial cost, cost of operation, gross and net income were made to determine the value on a basis of dollars and cents.

During a period of war, costs and values are increased enormously, and values are not measured in dollars but in time, necessity and quick availability for the purpose of ultimately saving life and vaster amounts of property and even the safety of the nation..

After the war, there must be a readjustment of values, and with this there should be a broader conception of values than that measured wholly in net returns of money.

The above outline of possible methods which might be used for the conservation of fuel is made for the purpose of describing in a general way the broader view which should be taken of this particular subject, and as an example of how the many other problems which have been summarized earlier should be attacked, not as a problem

by itself to be decided in terms of money as applied directly to that particular problem, but with careful consideration of the broader bearing upon the greatest good for the community or country. Such broad consideration as this will necessitate a remolding of our former circumscribed conceptions, a broadening of our imagination and the weighing of the effect of action and consequences in the broadest and most liberal manner.

As a people we should readjust our methods of life, getting down more nearly to the fundamentals, eliminating many extravagances and wastes in our private method of living, on our local, state and national governments, in education, in the industries and in all of our activities, so that we may not rob future generations of the heritage which is rightfully theirs, and so that we, ourselves, may by elimination of many cumbersome things, get a better perspective of what is necessary and right and live with a better conception of the real things of value on this earth. If we shall not have learned a lesson which will enable us to do so, a part of our suffering will have been in vain.

In closing I desire to quote from an article prepared by Honorable Joseph I. France, which is applicable to the present time and during the period of reconstruction:

"Scholars and members of these great academies, officials of states and nations, men in the armies, men and women in all our industries and at home, must catch a vision of this process and of this plan and strike strong, increasing, shaping, fabricating blows in order that in these fires America may be welded into that new and more nearly perfect symmetry and unity which will assure to each and to all the utmost safety and the highest liberty.

"In America the new temple of liberty is not yet builded, but it is in the building and it is for us, for each living American, an hour of opportunity and of destiny, in which we all must rededicate ourselves unreserved to sacrifice, to toil and to unwearying service until the nobler and more lofty fane is fully complete."

No. 1654

REPORT OF THE COMMITTEE ON STANDARDIZATION OF FLANGES AND PIPE FITTINGS

To the Council of the American Society of Mechanical Engineers:

Your Committee on the Standardization of Flanges and Pipe Fittings has agreed on the following additions to existing standards comprised in its report known as The American Standard for Pipe Flanges, Fittings and their Bolting, issued in 1914, and herewith presents them for your consideration and action:

Standardization of angle elbows and special angle fittings: From 1 deg. to 45 deg.: use center-to-face dimensions of standard 45-deg. elbows, American Standard, and over 45 deg., use center-to-face dimensions given for 90 deg. American Standard elbows.

1 A standard to be known as American Low-Pressure Standard for 50 lb. working pressure, tabulation of flange data attached. This standard was recommended after an agreement with the Committee of the Manufacturers' Association.

2 Three standards for hydraulic fittings, to be known as:

800-Lb. Hydraulic American Standard
1200-Lb. Hydraulic American Standard
3000-Lb. Hydraulic American Standard.

Tabulations and data for each of these standards with joint designs are submitted for your consideration. These are given in Tables 1 to 4, inclusive, and in Figs. 1, 2, and 3.

Your Committee deems it inadvisable at this time to outline or recommend a standard for 600 lb. steam pressure with superheat, partly because there is at present no demand for fittings for this

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pressure and because your Committee feels that it should be guided somewhat by experience in the field with the pressures and temperatures now in use, namely, 300 lb. pressure and 250 to 275 deg. superheat.

Your Committee, however, is ready to advise that for 400 lb. steam pressure and not exceeding 250 deg. superheat the 800-lb. Hydraulic American Standard in steel is adequate.

These recommendations bring the work of your Committee up to date so far as any requests that they have before them for consideration are concerned.

It is the desire of the Manufacturers' Association that the standards herein outlined be made effective at the earliest possible date. Your Committee, therefore, respectfully invites your early action.

Respectfully submitted,

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Committee on Standardization of Flanges and Pipe Fittings

TABLE 1 PROPOSED LOW-PRESSURE STANDARD FOR END FLANGES,* BOLTINGS AND BODY THICKNESS, — 50 LB. WORKING PRESSURE

Size	Diameter of Flange	Flange Thickness	Bolt-Circle Diameter	Number of Bolts	Size of Bolts	Body Thickness	Size	Diameter of Flange	Flange Thickness	Bolt-Circle Diameter	Number of Bolts	Size of Bolts	Body Thickness
12	19	$1\frac{1}{4}$	17	12	$\frac{3}{4}$	$\frac{5}{8}$	56	$68\frac{3}{4}$	3	65	48	$1\frac{1}{4}$	$1\frac{5}{8}$
14	21	$1\frac{3}{8}$	$18\frac{3}{4}$	12	$\frac{3}{4}$	$\frac{11}{16}$	58	71	$3\frac{1}{8}$	$67\frac{1}{4}$	48	$1\frac{1}{4}$	$1\frac{5}{8}$
15	$22\frac{1}{4}$	$1\frac{3}{8}$	20	16	$\frac{3}{4}$	$\frac{11}{16}$	60	73	$3\frac{1}{8}$	$69\frac{1}{4}$	52	$1\frac{1}{4}$	$1\frac{11}{16}$
16	$23\frac{1}{2}$	$1\frac{7}{16}$	$21\frac{1}{4}$	16	$\frac{3}{4}$	$\frac{3}{4}$	62	$75\frac{3}{4}$	$3\frac{1}{4}$	$71\frac{3}{4}$	52	$1\frac{1}{4}$	$1\frac{3}{4}$
18	25	$1\frac{9}{16}$	$22\frac{3}{4}$	16	$\frac{7}{8}$	$\frac{3}{4}$	64	78	$3\frac{1}{4}$	74	52	$1\frac{1}{4}$	$1\frac{3}{4}$
20	$27\frac{1}{2}$	$1\frac{11}{16}$	25	20	$\frac{7}{8}$	$\frac{13}{16}$	66	80	$3\frac{3}{8}$	76	52	$1\frac{1}{4}$	$1\frac{13}{16}$
22	$29\frac{1}{2}$	$1\frac{13}{16}$	$27\frac{1}{4}$	20	$\frac{7}{8}$	$\frac{7}{8}$	68	$82\frac{1}{4}$	$3\frac{3}{8}$	$78\frac{1}{4}$	56	$1\frac{1}{4}$	$1\frac{7}{8}$
24	32	$1\frac{7}{8}$	$29\frac{1}{2}$	20	$\frac{7}{8}$	$\frac{7}{8}$	70	$84\frac{1}{2}$	$3\frac{1}{2}$	$80\frac{1}{2}$	56	$1\frac{1}{4}$	$1\frac{15}{16}$
26	$34\frac{1}{4}$	2	$31\frac{3}{4}$	24	1	$\frac{15}{16}$	72	$86\frac{1}{2}$	$3\frac{1}{2}$	$82\frac{1}{2}$	60	$1\frac{1}{4}$	$1\frac{15}{16}$
28	$36\frac{1}{2}$	$2\frac{1}{16}$	34	28	1	1	74	$88\frac{1}{2}$	$3\frac{5}{8}$	$84\frac{1}{2}$	60	$1\frac{1}{4}$	2
30	$38\frac{3}{4}$	$2\frac{1}{8}$	36	28	1	1	76	$90\frac{3}{4}$	$3\frac{5}{8}$	$86\frac{1}{2}$	60	$1\frac{1}{4}$	$2\frac{1}{16}$
32	$41\frac{3}{4}$	$2\frac{1}{4}$	$38\frac{1}{2}$	28	1	$1\frac{1}{16}$	78	93	$3\frac{3}{4}$	$88\frac{3}{4}$	60	$1\frac{3}{8}$	$2\frac{1}{8}$
34	$43\frac{3}{4}$	$2\frac{5}{16}$	$40\frac{1}{2}$	32	1	$1\frac{1}{8}$	80	$95\frac{1}{4}$	$3\frac{3}{4}$	91	60	$1\frac{3}{8}$	$2\frac{1}{8}$
36	46	$2\frac{3}{8}$	$42\frac{3}{4}$	32	1	$1\frac{1}{8}$	82	$97\frac{1}{2}$	$3\frac{7}{8}$	$93\frac{1}{4}$	60	$1\frac{3}{8}$	$2\frac{3}{16}$
38	$48\frac{3}{4}$	$2\frac{3}{8}$	$45\frac{1}{4}$	32	$1\frac{1}{8}$	$1\frac{3}{16}$	84	$99\frac{3}{4}$	$3\frac{7}{8}$	$95\frac{1}{2}$	64	$1\frac{3}{8}$	$2\frac{1}{4}$
40	$50\frac{3}{4}$	$2\frac{1}{2}$	$47\frac{1}{4}$	36	$1\frac{1}{8}$	$1\frac{1}{4}$	86	102	4	$97\frac{3}{4}$	64	$1\frac{3}{8}$	$2\frac{1}{4}$
42	53	$2\frac{5}{8}$	$49\frac{1}{2}$	36	$1\frac{1}{8}$	$1\frac{1}{4}$	88	$104\frac{1}{4}$	4	100	68	$1\frac{3}{8}$	$2\frac{5}{16}$
44	$55\frac{1}{4}$	$2\frac{5}{8}$	$51\frac{3}{4}$	40	$1\frac{1}{8}$	$1\frac{5}{16}$	90	$106\frac{1}{2}$	$4\frac{1}{8}$	$102\frac{1}{4}$	68	$1\frac{3}{8}$	$2\frac{3}{8}$
46	$57\frac{1}{4}$	$2\frac{11}{16}$	$53\frac{3}{4}$	40	$1\frac{1}{8}$	$1\frac{3}{8}$	92	$108\frac{3}{4}$	$4\frac{1}{8}$	$104\frac{1}{2}$	68	$1\frac{3}{8}$	$2\frac{3}{8}$
48	$59\frac{1}{2}$	$2\frac{3}{4}$	56	44	$1\frac{1}{8}$	$1\frac{7}{16}$	94	111	$4\frac{1}{8}$	$106\frac{1}{4}$	68	$1\frac{3}{8}$	$2\frac{7}{16}$
50	$61\frac{3}{4}$	$2\frac{3}{4}$	$58\frac{1}{4}$	44	$1\frac{1}{8}$	$1\frac{1}{2}$	96	$113\frac{1}{4}$	$4\frac{1}{8}$	$108\frac{1}{2}$	68	$1\frac{3}{8}$	$2\frac{1}{2}$
52	64	$2\frac{7}{8}$	$60\frac{1}{2}$	44	$1\frac{1}{8}$	$1\frac{1}{2}$	98	$115\frac{1}{2}$	$4\frac{3}{8}$	$110\frac{3}{4}$	68	$1\frac{3}{8}$	$2\frac{1}{2}$
54	$66\frac{1}{4}$	3	$62\frac{3}{4}$	44	$1\frac{1}{8}$	$1\frac{9}{16}$	100	$117\frac{3}{4}$	$4\frac{3}{8}$	113	68	$1\frac{3}{8}$	$2\frac{9}{16}$

NOTE

1 For sizes 10 in. and smaller, use regular 125-lb. American Standard flange dimensions and templets.

2 For sizes 12 in. and larger, use 125-lb. American Standard flange diameters, bolt circles, and number of bolts, using bolt diameters as shown above, thereby maintaining interchangeability with 125-lb. American Standard flanges.

3 Screwed companion flanges should not be thinner than 125-lb. American Standard thickness.

TABLE 2 800-LB. HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS, 12 IN. AND SMALLER, FOR FULL-WEIGHT WROUGHT PIPE. SEMI-STEEL AND CAST STEEL. (See Fig. 1)

800 Lb. Cold Water Working Pressure — Hydrostatic (no shock)
500 Lb. Cold Water Working Pressure — Shock
800 Lb. Air or Gas Working Pressure — Temperature Not Exceeding 100 Deg. Fahr.

See Fig. 1	Size	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12
A	Inside diameter of port	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12
B	Center to face, ell, tee, cross	3¼	3¾	4¼	4½	4¾	5¾	6½	7	7½	8½	9	10	11	12	13	14½	15½	16½
C	Face to face, tee, cross, reducer	6½	7½	8½	9	9½	11½	13	14	15	17	18	20	22	24	26	29	31	33
D	Center to face, 45-deg. ell	2	2¼	2½	2¾	3	4¼	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10
E	Center to face, lateral	5½	6	6¾	7½	8¼	11	12½	13½	14½	16½	17½	19½	21	22½	24½	27½	29½	31½
F	Center to face, lateral	1¾	2	2¼	2½	2¾	3½	3½	4	4½	4½	5½	6	6½	6½	7	7½	8	8½
G	Face to face, lateral	7¼	8	9	10	11½	14½	16	17½	19	21	23	25½	27½	29	31½	35	37½	40
H	Diameter of flange	3½	4	4½	5	6	7	7½	8½	9½	10¾	11½	13	14	15	16½	18½	20	22
K	Thickness of flange — Semi-steel	9/16	5/8	11/16	¾	13/16	1¼	1⅜	1½	1⅝	1⅞	2	2⅛	2¼	2⅜	2½	2¾	2⅞	3
	Thickness of flange — Cast steel	..	..	..	..	..	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2⅜	2½	2⅝
L	Diameter of raised face	1⅜	1 11/16	2	2¼	2⅞	3⅝	4⅛	5	5½	6	6½	7¼	8⅝	9⅜	10⅝	11⅝	12¾	15¼
M	Height of raised face	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼
N	Minimum metal thickness — Semi-steel	7/16	7/16	½	½	½	9/16	⅝	⅝	¾	⅞	1	1⅛	1⅛	1¼	1⅜	1½	1⅝	1¾
	Minimum metal thickness — Cast steel	..	..	..	..	..	½	9/16	9/16	⅝	11/16	¾	13/16	⅞	1	1 1/16	1⅛	1¼	1⅜
	Diameter of bolt circle	2⅜	2⅞	3¼	3¾	4½	5¼	5⅞	6½	7½	8½	9¼	10½	11½	12½	13¾	15½	17	19¼
	Number of bolts	4	4	4	4	4	4	8	8	8	8	8	8	12	12	12	16	16	20
	Diameter of bolts	7/16	½	½	½	⅝	¾	¾	¾	⅞	⅞	⅞	1	1	1	1⅛	1⅛	1¼	1¼
	Length of bolts — Semi-steel	2¼	2½	2½	2¾	3	4	4¼	4½	4¾	5¼	5½	6	6¼	6½	7	7½	7¾	8
	Length of bolts — Cast steel	..	..	..	..	..	3½	3¾	4	4¼	4½	4¾	5¼	5½	5¾	6¼	6¾	7	7¼

These fittings are recommended for pump columns, oil-transmission lines, gas lines and other hydraulic service where shock is negligible for a maximum working pressure of 800 lb. and a maximum temperature of 100 deg. fahr. Where subject to shock they are recommended for a maximum working pressure of 500 lb.

The diameter of port is nominal size.

Reducing fittings carry same dimensions center to face as straight-size fittings corresponding to largest opening.

Flanges may be attached to the pipe by any of the following methods: Screw flanges; lap flanges; shrunk, peened or riveted flanges; flanges welded to pipe.

Flanges on fittings and valves, also all companion flanges except those for lap joint, should be furnished with ¼-in. raised face, as shown in dimension table, Fig. 2, unless otherwise specified.

Bolt holes are ⅛ in. larger in diameter than bolts. Bolt holes straddle center lines. Unless otherwise specified, bolt holes in cast-steel fittings should be spot-faced.

Square-head bolts with hexagonal nuts are recommended. Hexagonal nuts on sizes 8 in. and smaller can be conveniently pulled up with open-end wrenches with minimum-design heads. Hexagonal nuts on sizes 9 in. and larger can be conveniently pulled up with box wrenches.

When flanges are screwed, shrunk, peened or riveted on the pipe, it is recommended that the end of the pipe and flange be refaced.

Gaskets extending from the inside of the pipe to the inside edge of the bolts are recommended. The ultimate compressive strength of the gasket must be sufficient to prevent its being crushed when bolts are pulled up.

Where long-radius elbows are desired, the use of nine bends is recommended

TABLE 3 1200-LB. HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS, 12 IN. AND SMALLER, FOR EXTRA STRONG WROUGHT PIPE. SEMI-STEEL AND CAST STEEL. (See Fig. 1)

1200 Lb. Cold Water Working Pressure — Hydrostatic (no shock)
800 Lb. Cold Water Working Pressure — Shock
1200 Lb. Air or Gas Working Pressure — Temperature Not Exceeding 100 Deg. Fahr.

See Fig. 1	Size	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	6	7	8	9	10	12
A	Inside diameter of port	1/2	3/4	13/16	1 1/4	1 1/2	1 7/8	2 1/4	2 3/4	3 1/4	3 3/4	4 1/4	4 3/4	5 3/4	6 3/4	7 5/8	8 3/4	9 3/4	11 3/4
B	Center to face, ell, tee, cross	3 1/2	4	4 1/2	5	5 1/2	6 1/2	7	7 1/2	8 1/2	9	10	11	12	13	14 1/2	15 1/2	16 1/2	17 1/2
C	Face to face, tee, cross, reducer	7	8	9	10	11 1/2	13	14	15	17	18	20	22	24	26	29	31	33	35
D	Center to face, 45-deg. ell	2 1/2	3	3 1/2	4	4 1/4	4 1/2	5	5 1/2	6	6 1/2	7	7 1/2	8	8 1/2	9	9 1/2	10	11
E	Center to face, lateral	7	8	9	10	11	12 1/2	13 1/2	14 1/2	16 1/2	17 1/2	19 1/2	21	22 1/2	24 1/2	27 1/2	29 1/2	31 1/2	34 1/2
F	Center to face, lateral	2	2 1/2	2 1/2	3	3 1/2	3 1/2	4	4 1/2	4 1/2	5 1/2	6	6 1/2	6 1/2	7	7 1/2	8	8 1/2	9
G	Face to face, lateral	9	10 1/2	11 1/2	13	14 1/2	16	17 1/2	19	21	23	25 1/2	27 1/2	29	31 1/2	35	37 1/2	40	43 1/2
H	Diameter of flange	4 1/4	4 3/4	5 1/2	6	6 3/4	8	8 1/2	9 1/2	10 3/4	11 1/2	13	14	15	16 1/2	18 1/2	20	21 1/2	24
K	Thickness of flange — Semi-steel	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 3/4	2 7/8	3	3 1/8
	Thickness of flange — Cast steel	..	..	..	..	..	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 3/8	2 1/2	2 5/8	2 3/4
L	Diameter of raised face	1 3/8	1 11/16	2	2 1/4	2 7/8	3 5/8	4 1/8	5	5 1/2	6	6 1/2	7 1/4	8 3/8	9 1/8	10 5/8	11 7/8	12 3/4	15 1/4
M	Height of raised face	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
N	Minimum metal thickness — Semi-steel	1/2	1/2	9/16	9/16	5/8	3/4	7/8	1	1 1/16	1 1/8	1 1/8	1 3/8	1 1/4	1 3/8	2	2 1/8	2 1/4	2 1/2
	Minimum metal thickness — Cast steel	..	..	..	..	..	5/8	11/16	13/16	7/8	1	1 1/16	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8
	Diameter of bolt circle	3	3 1/8	4	4 1/8	4 7/8	6	6 1/2	7 1/2	8 1/2	9 1/4	10 1/2	11 1/2	12 1/2	13 3/4	15 1/2	17	18 1/2	21
	Number of bolts	4	4	4	4	4	4	8	8	8	8	8	8	12	12	12	16	16	20
	Diameter of bolts	1/2	1/2	5/8	5/8	3/4	7/8	7/8	7/8	1	1	1 1/8	1 1/8	1 1/8	1 1/4	1 3/8	1 3/8	1 3/8	1 3/8
	Length of bolts — Semi-steel	2 3/4	3	3 1/4	3 1/2	4	4 1/2	4 1/2	4 3/4	5 1/2	5 3/4	6 1/4	6 1/2	6 3/4	7	7 3/4	8	8 1/4	8 1/2
	Length of bolts — Cast steel	..	..	..	..	..	3 3/4	4	4 1/4	4 1/4	5	5 1/2	5 3/4	6	6 1/4	7	7 1/4	7 1/2	7 3/4

These fittings are recommended for pump columns, oil-transmission lines, gas lines and other hydraulic service where shock is negligible for a maximum working pressure of 1200 lb. and a maximum temperature of 100 deg. fahr. Where subject to shock they are recommended for a maximum working pressure of 800 lb.

The diameter of port is approximately the same as the inside diameter of Extra Strong Pipe.

Reducing fittings carry the same dimensions center to face as straight-size fittings corresponding to largest opening.

Flanges may be attached to the pipe by any of the following methods: Screw flanges; lap flanges; shrunk, peened or riveted flanges; flanges welded to pipe.

Flanges on fittings and valves, also all companion flanges except those for lap joint, should be furnished with 1/16-in. raised face, as shown in dimension table, Fig. 2, unless otherwise specified.

Bolt holes are 1/8 in. larger in diameter than bolts. Bolt holes straddle center lines. Unless otherwise specified, bolt holes in cast-steel fittings should be spot-faced.

Square-head bolts with hexagonal nuts are recommended. Hexagonal nuts on sizes 8 in. and smaller can be conveniently pulled up with open-end wrenches with minimum-design heads. Hexagonal nuts on sizes 9 in. and larger can be conveniently pulled up with box wrenches.

When flanges are screwed, shrunk, peened or riveted on the pipe, it is recommended that the end of the pipe and flange be refaced.

Gaskets extending from the inside of the pipe to the inside edge of the bolts are recommended. The ultimate compressive strength of the gasket must be sufficient to prevent its being crushed when the bolts are pulled up.

Where long-radius elbows are desired, the use of pipe bends is recommended.

TABLE 4 3000-LB. HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS, 12 IN. AND SMALLER, FOR DOUBLE EXTRA STRONG WROUGHT PIPE. CAST STEEL. (See Fig. 1)

3000 Lb. Cold Water Working Pressure — Hydrostatic (no shock)
2000 Lb. Cold Water Working Pressure — Shock
3000 Lb. Air or Gas Working Pressure — Temperature Not Exceeding 100 Deg. Fahr.

See Fig. 1	Size	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12
A	Inside diameter of port	⅜	½	¾	15/16	1¼	1½	1⅞	2¼	2¾	3¼	3¾	4¼	4¾	5¾	6¾	7⅝	8¾	10¾
B	Center to face, ell, tee, cross	3½	4	4½	5	5¾	6½	7	7½	8½	9	10	11	12	13	14½	15½	16½	17½
C	Face to face, tee, cross, reducer	7	8	9	10	11½	13	14	15	17	18	20	22	24	26	29	31	33	35
D	Center to face, 45-deg. ell	2½	3	3½	4	4¼	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	11
E	Center to face, lateral	7	8	9	10	11	12½	13½	14½	16½	17½	19½	21	22½	24½	27½	29½	31½	34½
F	Center to face, lateral	2	2½	2½	3	3½	3½	4	4½	4½	5½	6	6½	6½	7	7½	8	8½	9
G	Face to face, lateral	9	10½	11½	13	14½	16	17½	19	21	23	25½	27½	29	31½	35	37½	40	43½
H	Diameter of flange	4¼	4¾	5½	6	6¾	8	8½	9½	10¾	11½	13	14	1	16½	18½	20	21½	24
K	Thickness of flange	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1⅞	2	2⅛	2¼	2⅜	2½	2¾	2⅞	3	3⅛
L	Diameter of raised face	⅞	1 1/16	1 5/16	1 13/16	1 15/16	2⅜	2⅞	3½	4	4½	5	5 9/16	6⅝	7⅝	8⅝	9⅝	10¾	12¾
M	Height of raised face	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼
N	Minimum metal thickness	7/16	½	½	9/16	9/16	⅝	¾	⅞	1	1 3/16	1⅛	1½	1⅝	1¾	1⅞	2	2⅛	2⅜
	Diameter of bolt circle	3	3½	4	4½	4⅞	6	6½	7½	8½	9¼	10½	11½	12½	13¾	15½	17	18½	21
	Number of bolts	4	4	4	4	4	4	8	8	8	8	8	8	12	12	12	16	16	20
	Diameter of bolts	½	⅝	⅝	¾	⅞	⅞	⅞	1	1	1⅛	1¼	1¼	1¼	1⅜	1½	1½	1½	1½
	Length of bolts	2¾	3	3¼	3¾	4	4¼	4½	5	5½	6	6¼	6½	6¾	7¼	7¾	8	8¼	8½

These fittings are recommended for hydraulic service where shock is negligible for a maximum working pressure of 3000 lb. and a maximum temperature of 100 deg. fahr. Where subject to shock they are recommended for a maximum working pressure of 2000 lb.

The diameter of port is approximately the same as the inside diameter of Double Extra Strong Pipe.

Reducing fittings carry same dimensions center to face as straight-size fittings corresponding to largest opening.

Flanges may be attached to the pipe by either of the following methods: Screw flanges; flanges welded to pipe.

Flanges on fittings and valves should be furnished with ⅛-in. raised face, as shown in dimension table, Fig. 3, unless otherwise specified.

Screw flanges are furnished with plain face and are threaded with American Briggs Standard lock-nut threads. The pipe should be threaded with American Briggs Standard lock-nut threads, and the end of the pipe should be faced off square. The pipe should be screwed through the flange until the end projects about ⅛ in. beyond the face of the flange and bears against the gasket.

When flanges are welded on the pipe the end of the pipe should project through the flange and should be faced off square to form the raised face.

Bolt holes are ⅛ in. larger in diameter than bolts. Bolt holes straddle center lines. Unless otherwise specified, bolt holes should be spot-faced.

Square-head bolts with hexagonal nuts are recommended. Hexagonal nuts on sizes 5 in. and smaller can be conveniently pulled up with open-end wrenches with minimum-design heads. Hexagonal nuts on sizes 6 in. and larger can be conveniently pulled up with box wrenches.

Gaskets extending from the inside of the pipe to the inside edge of the bolts are recommended. The ultimate compressive strength of the gasket must be sufficient to prevent its being crushed when the bolts are pulled up. Soft metallic gaskets at least 1/16 in. thick are recommended.

Where long-radius elbows are desired, the use of pipe bends is recommended.

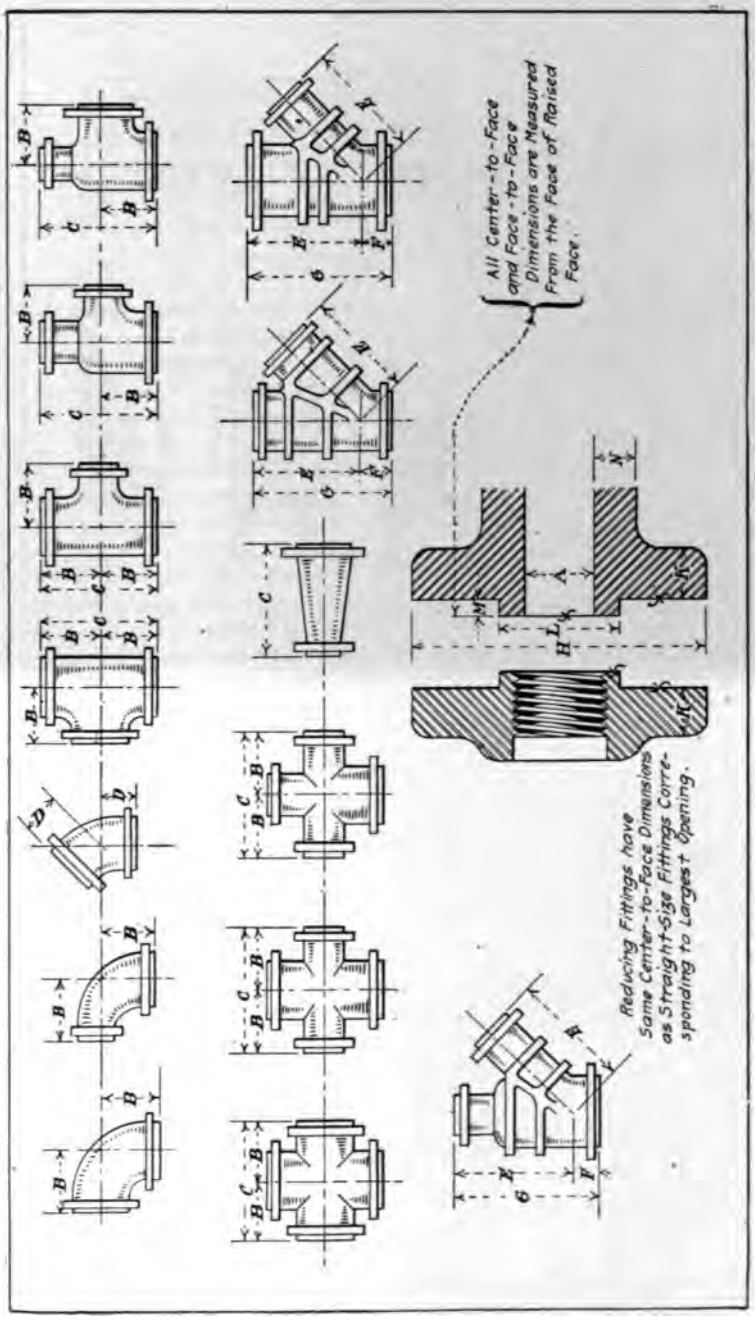
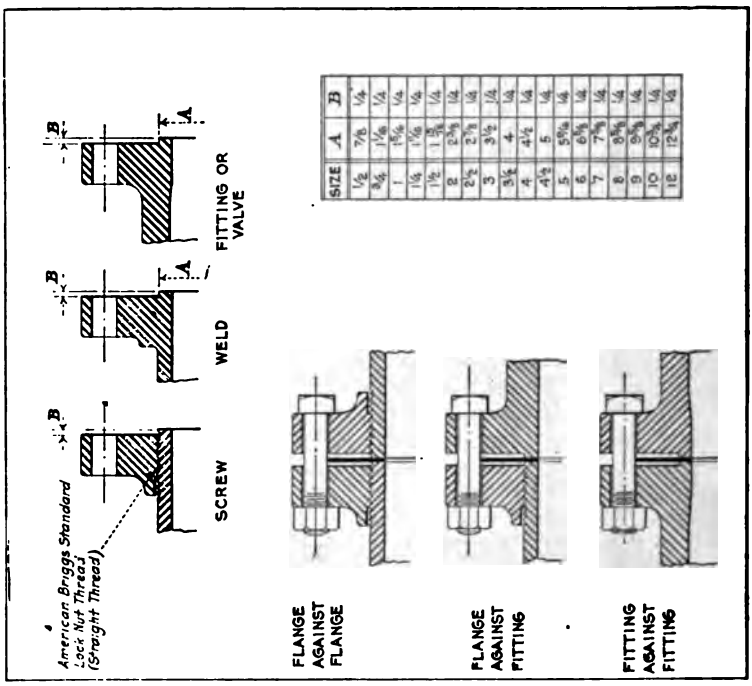
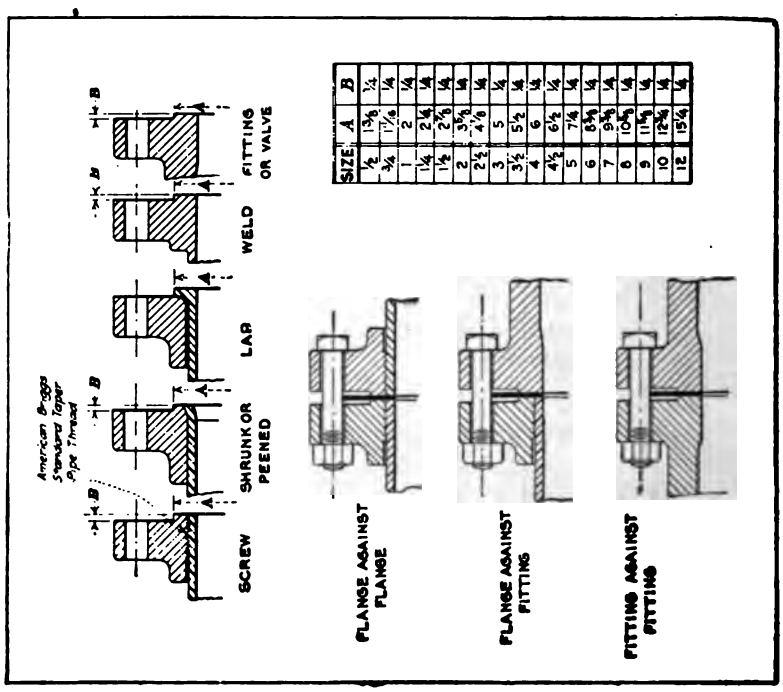


FIG. 1 HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS DIMENSIONED IN TABLES 2, 3 AND 4



SIZE	A	B
½	⅞	¼
¾	1⅛	¼
1	1⅜	¼
1¼	1⅝	¼
1½	1⅞	¼
2	2⅜	¼
2½	2⅞	¼
3	3½	¼
3½	4	¼
4	4½	¼
4½	5	¼
5	5⅝	¼
6	6⅝	¼
7	7⅝	¼
8	8⅝	¼
9	9⅝	¼
10	10⅝	¼
12	12⅝	¼

FIG. 3 FLANGE JOINTS AND METHODS OF ATTACHING FLANGES TO PIPE, 3000-LB. HYDRAULIC AMERICAN STANDARD



SIZE	A	B
½	1⅜	¼
¾	1⅞	¼
1	2	¼
1¼	2⅛	¼
1½	2⅜	¼
2	3⅜	¼
2½	4⅛	¼
3	5	¼
3½	5½	¼
4	6	¼
4½	6½	¼
5	7⅛	¼
6	8⅝	¼
7	9⅝	¼
8	10⅝	¼
9	11⅝	¼
10	12⅝	¼
12	15¼	¼

FIG. 2 FLANGE JOINTS AND METHODS OF ATTACHING FLANGES TO PIPE, 800-LB. AND 1200-LB. HYDRAULIC AMERICAN STANDARD

No. 1655

PROPERTIES OF AIRPLANE FABRICS

By E. Dean Walen, Boston, Mass.
Junior Member of the Society

The author presents a brief résumé of the history of the development of cotton airplane fabrics and discusses the methods of determining the properties of airplane fabrics, with particular reference to the defining of the quantities determined, the apparatus used and the interpretation of the results obtained.

He then discusses a few typical examples of satisfactory and unsatisfactory fabrics. The purpose of the paper is to acquaint the reader with the fundamentals underlying the investigation, rather than to burden him with the tiresome details of the actual experimentation.

It is believed that there is presented a concept of textiles which, so far as is known, has been but little considered, consisting of an analysis of fabrics in much the same manner as other more commonly known structural materials are studied.

The subject suggests that the investigation applies to a very limited class of fabrics, but many of the fundamentals discussed are applicable to the study of many of the fabrics used for more familiar purposes and of more general interest than airplane fabrics.

THE design of heavier-than-air machines during their early stages of development was arrived at by cut-and-try methods. The wings of such machines were covered with plain cotton fabric, much the same as an ordinary sheeting material, coated with a beeswax compound or some form of glue. The wing surfaces were then rubbed and polished to present a surface having a comparatively low skin friction. Such a covering was not very strong and sagged very materially when subjected to pressure and when exposed to weather.

2 As the application of science produced planes which were capable of much higher speeds, smaller wing surfaces, and a consequently increased loading per square foot of wing surface, it became necessary to cover them with a material having a high strength and a low weight.

3 It was generally known that flax spun into yarns and subsequently woven into fabrics produced a very tough material having little stretch and the property of withstanding shocks with very little permanent set.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

4 Accordingly, unbleached linen fabric was used to cover the wings of planes and found to be very satisfactory. The structure of the linen fabric is that of an ordinary fine linen sheeting. No attempts had been made to study the requirements of the covering material or to design a fabric meeting those requirements which might possibly be lighter and more resistant than the linen fabrics.

5 During the present crisis it became evident that the available supply of linen would not suffice the demands of the military programs of the countries at war, and it became necessary to find materials which could be used in place of the satisfactory linen.

6 As early as January 1916 the Bureau started investigating the possibilities of substituting cotton for linen airplane fabrics, and found that the general consensus of opinion among airplane manufacturers and investigators here and abroad was that the use of cotton fabric for wing coverings was out of the question, as many experiments had already been made to substantiate these opinions.

7 However, we were certain that not all the possibilities of structure of fabric had been considered, and we began an investigation to study the stresses in a fabric on a plane and to thoroughly determine by actual measurement the properties of the linen fabric and to incorporate the desirable properties of the linen in a cotton fabric suited for the purpose.

8 The difficulties experienced in the experiments on cotton fabrics previous to the time of our investigations were: (*a*) low strength per unit of weight; (*b*) low tearing resistance; (*c*) little shrinkage upon application of dope; (*d*) little tendency to retain what little shrinkage they had after doping.

9 It was not until March 18, 1917, that we were in a position to issue instructions covering the construction of cotton fabrics for the experimental fabrics which proved to be quite successful. These instructions were sent to the various fine-goods cotton mills and were supplemented by visits of our textile experts to the mills.

10 At the mills our textile men sat down with the practical men and evolved the present cotton airplane fabrics. At this point I wish to mention the name of Mr. Ricketson, agent of the Pontoosuc Mills, as he did much to make cotton fabrics a success.

11 The first fabrics of this series were received at the Bureau on or about the first of April 1917, and as the series progressed we suggested changes, and during the early part of May 1917 a fabric had successfully passed our laboratory standards. The next important problem was to determine the actual performance of these

fabrics. To this end samples were placed on Army planes at Langley Field and Navy planes at Pensacola during August 1917. Similar fabrics were later sent by the Signal Corps to the Canadian Aeroplane Company, of Toronto, Canada, and they were placed on planes the middle of October 1917.

12 The results of the service tests demonstrated that the fabrics were satisfactory and that service results could be reliably predicted in the laboratory. In view of this we felt justified in modifying the structure of these fabrics, and in coöperation with Mr. R. L. Kingston, then with the Curtiss Aeroplane Company, and with Mr. A. R. Pierce, of the Pierce Manufacturing Company, the present Grade A cotton fabric was evolved.

13 It was not until August that the military authorities were becoming concerned with the scarcity of linen, and on or about the 23d of August the Joint Army and Navy Aircraft Board called the Bureau into a conference regarding cotton fabrics for airplanes, and we were able to say with a great degree of certainty that we had a fabric ready for their needs.

14 On August 24, 1917, a conference held between the military authorities and representatives of the Bureau resulted in the Signal Corps Equipment Division ordering that the Bureau of Standards supply the necessary specifications covering the purchase of 500,000 yd. of airplane cotton fabric. The specifications were transmitted by the Bureau of Standards on September 5, 1917, covering the fabrics now known as Grade A and Grade B as used by the Signal Corps and Navy. A few days later the Bureau supplied the necessary information regarding the apparatus and methods of testing and inspection.

15 The Department of Agriculture was invited by this Bureau to assist in further development, and the experiments were started during September 1917, but because of some unfortunate circumstance we were unable to keep in touch with the work. During April 1918 the Signal Corps submitted samples which we understood to be the result of these investigations. They dealt with the use of the various cottons and the experiments were very valuable.

16 Recently the standard fabrics were submitted to the English airplane authorities and their comments were to the effect that the results of their tests were astonishingly successful. Since that time the English have adopted the standard Grade A fabric.

17 At the time we were making our field tests at Langley, the Italian Aviation Mission was there. One of their planes was covered

with a cotton fabric which they had used successfully on the battle front, and the members of that Mission offered the opinion that our fabrics were better than their own successful fabric. It is a peculiar thing that upon analysis this fabric differed but slightly from our own as far as thread count and yarn number were concerned. Here were two people working on the same problems, on opposite sides of the water and having no information regarding each other's work, and the results were practically the same.

18 It is necessary to determine the requirements which a material must satisfy, together with the properties of the material being substituted, before suitable substitutes can be found.

19 This discussion treats of the methods of determining the properties of textile materials from which may be determined their compliance with the requirements of airplane wing coverings.

METHOD OF COVERING AIRPLANE WINGS

20 It is thought advisable to discuss briefly the method of covering airplane wings in order that one may follow the discussion with more interest. The frame of an airplane wing is covered with a fabric according to one of the following methods: The fabric is sewed into a piece which is wide enough to cover, and is folded completely over and under, the wing frame. It is then tacked on the three open sides after being stretched just enough to take out the wrinkles. The raw edges of the fabric are then sewed together and the tacks removed. The other method consists in making of a pocket of fabric and slipping it over the frame. The open end is then tacked and sewed the same as in the previous case. The system of threads in the fabric may have the following two relations to the major and minor axes of the wing: The warp running from the "leading in" edge to the "trailing" edge, or parallel to the short or minor axis of the wing; or it may be put on such that the warp is at 45 deg. to the axis of the wing. The fabric is laced to the wing ribs at intervals of about six inches. After the fabric is on the frame, it is treated by means of a brush with a solution of cellulose acetate or nitrate with suitable stabilizers, etc., which is termed "dope." The dope has the property of producing a tight drumhead-like wing covering, which is often attributed to the shrinking of the fabric. It also serves to fill in the interstices of the fabric, making a surface which has a coefficient of friction to air approximately equal to that of plate glass. The doped wing fabric may be considered as a rectangular membrane fixed at two sides and supported on the other

two sides by the ribs of the frame, and that the wing is composed of many of these sections.

DETERMINATIONS OF THE PROPERTIES OF UNDOPED FABRICS

21 *Moisture.* The fact that all fibers, either animal or vegetable, absorb moisture in varying amounts is very well known. The effect of the moisture absorbed is little considered other than it affects the weight determinations.

22 For the purposes of this paper it is sufficient to know that the physical properties change in value with a change in the moisture content of the specimen, and that the changes of the properties of the various vegetable fibers are very much of the same order.

23 In view of this, it is necessary to either fix the moisture content of the materials being tested, or to expose them to a constant and known atmosphere. The ability of a material to absorb moisture is a distinct property of that material, and any method which fixes the moisture content does not allow of the accurate determination of the properties.

24 The moisture content of the test specimens is that absorbed by the material when exposed to an atmosphere of 65 per cent relative humidity at 21 deg. cent. until the moisture of the sample is in equilibrium with that of the atmosphere. This condition of atmosphere will be considered in this paper as a standard for the accurate determinations of the properties of textile materials. The amount of moisture is found by drying the sample to a constant weight in a ventilated drying oven maintained at a temperature of 110 deg. cent., and expressing the difference in weight from the conditioned weight in terms of the bone-dry weight. This is commonly termed "regain."

25 *Weight.* Pieces of 4 sq. in. are cut from various parts of the sample and weighed after exposure to the standard atmosphere, and the results expressed in terms of weight per unit of area. The commercial method of determining the weight per unit of area involves the measuring and weighing of an entire roll. A casual consideration of the two methods would lead to the conclusion that the latter procedure would give the more satisfactory result. However, the tension during measuring is not a constant or known amount. The variation in tension introduces an error, and the weights determined by this method usually run lighter than those determined from the small samples.

26 *Length of Yarn.* The length of a yarn is considered to be

TABLE 4 3000-LB. HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS, 12 IN. AND SMALLER, FOR DOUBLE EXTRA STRONG WROUGHT PIPE. CAST STEEL. (See Fig. 1)

3000 Lb. Cold Water Working Pressure — Hydrostatic (no shock)
2000 Lb. Cold Water Working Pressure — Shock
3000 Lb. Air or Gas Working Pressure — Temperature Not Exceeding 100 Deg. Fahr.

See Fig. 1	Size	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12
A	Inside diameter of port	⅜	½	¾	15/16	1¼	1½	1⅞	2¼	2¾	3¼	3¾	4¼	4¾	5¾	6¾	7⅝	8¾	10¾
B	Center to face, ell, tee, cross	3½	4	4½	5	5¾	6½	7	7½	8½	9	10	11	12	13	14½	15½	16½	17½
C	Face to face, tee, cross, reducer	7	8	9	10	11½	13	14	15	17	18	20	22	24	26	29	31	33	35
D	Center to face, 45-deg. ell	2½	3	3½	4	4¼	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	11
E	Center to face, lateral	7	8	9	10	11	12½	13½	14½	16½	17½	19½	21	22½	24½	27½	29½	31½	34½
F	Center to face, lateral	2	2½	2½	3	3½	3½	4	4½	4½	5½	6	6½	6½	7	7½	8	8½	9
G	Face to face, lateral	9	10½	11½	13	14½	16	17½	19	21	23	25½	27½	29	31½	35	37½	40	43½
H	Diameter of flange	4¼	4¾	5½	6	6¾	8	8½	9½	10¾	11½	13	14	1	16½	18½	20	21½	24
K	Thickness of flange	¾	¾	1	1⅛	1¼	1⅜	1½	1⅝	1⅞	2	2⅛	2¼	2⅜	2½	2¾	2⅞	3	3⅛
L	Diameter of raised face	⅞	1 1/16	1 5/16	1 11/16	1 15/16	2⅜	2⅞	3½	4	4½	5	5 9/16	6⅝	7⅝	8⅝	9⅝	10¾	12¾
M	Height of raised face	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼
N	Minimum metal thickness	7/16	½	½	9/16	9/16	⅝	¾	⅞	1	1 1/16	1⅛	1½	1⅝	1¾	1⅞	2	2⅛	2⅜
	Diameter of bolt circle	3	3⅜	4	4⅜	4⅞	6	6½	7½	8½	9¼	10½	11½	12½	13¾	15½	17	18½	21
	Number of bolts	4	4	4	4	4	4	8	8	8	8	8	8	12	12	12	16	16	20
	Diameter of bolts	½	⅝	⅝	¾	⅞	⅞	⅞	1	1	1⅛	1¼	1¼	1¼	1⅜	1½	1½	1½	1½
	Length of bolts	2¼	3	3¼	3¾	4	4¼	4½	5	5½	6	6¼	6½	6¾	7¼	7¾	8	8¼	8½

These fittings are recommended for hydraulic service where shock is negligible for a maximum working pressure of 3000 lb. and a maximum temperature of 100 deg. fahr. Where subject to shock they are recommended for a maximum working pressure of 2000 lb.

The diameter of port is approximately the same as the inside diameter of Double Extra Strong Pipe.

Reducing fittings carry same dimensions center to face as straight-size fittings corresponding to largest opening.

Flanges may be attached to the pipe by either of the following methods: Screw flanges; flanges welded to pipe.

Flanges on fittings and valves should be furnished with ¼-in. raised face, as shown in dimension table, Fig. 3, unless otherwise specified.

Screw flanges are furnished with plain face and are threaded with American Briggs Standard lock-nut threads. The pipe should be threaded with American Briggs Standard lock-nut threads, and the end of the pipe should be faced off square. The pipe should be screwed through the flange until the end projects about ¼ in. beyond the face of the flange and bears against the gasket.

When flanges are welded on the pipe the end of the pipe should project through the flange and should be faced off square to form the raised face.

Bolt holes are ⅛ in. larger in diameter than bolts. Bolt holes straddle center lines. Unless otherwise specified, bolt holes should be spot-faced.

Square-head bolts with hexagonal nuts are recommended. Hexagonal nuts on sizes 5 in. and smaller can be conveniently pulled up with open-end wrenches with minimum-design heads. Hexagonal nuts on sizes 6 in. and larger can be conveniently pulled up with box wrenches.

Gaskets extending from the inside of the pipe to the inside edge of the bolts are recommended. The ultimate compressive strength of the gasket must be sufficient to prevent its being crushed when the bolts are pulled up. Soft metallic gaskets at least 1/16 in. thick are recommended.

Where long-radius elbows are desired, the use of pipe bends is recommended.

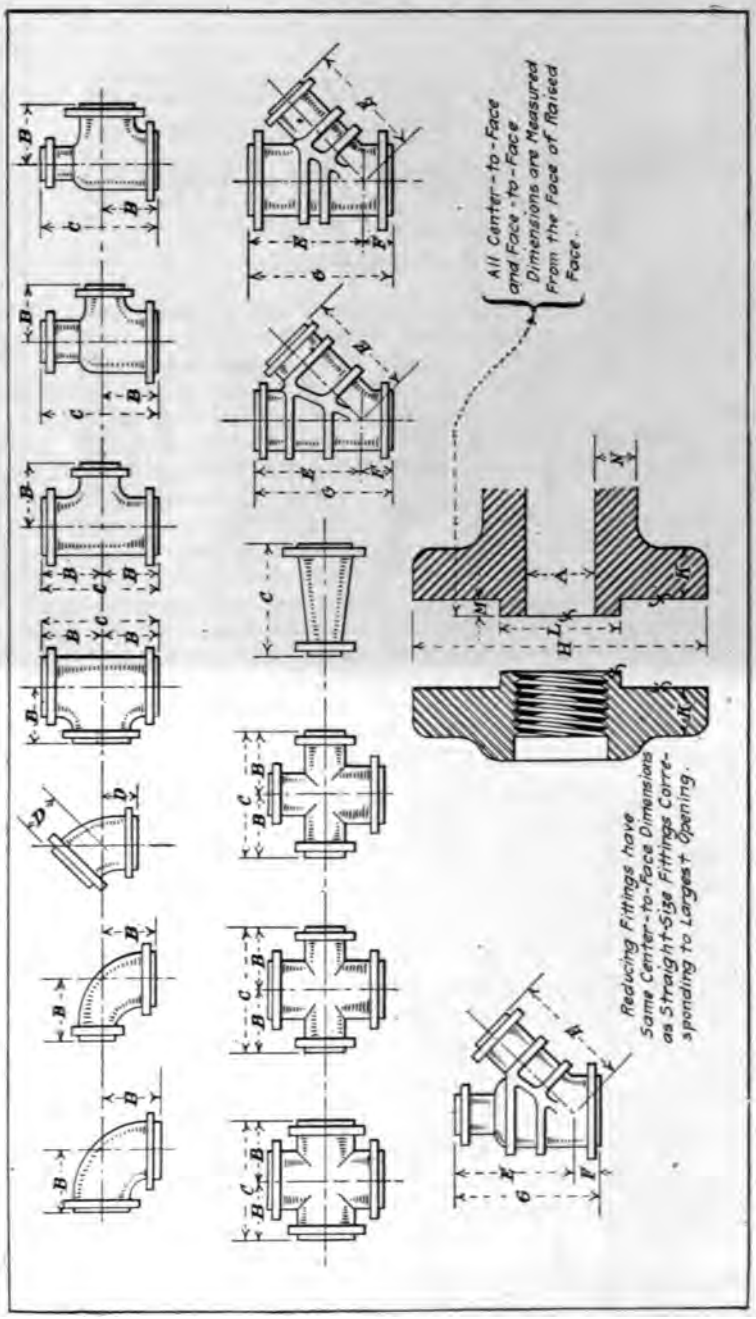
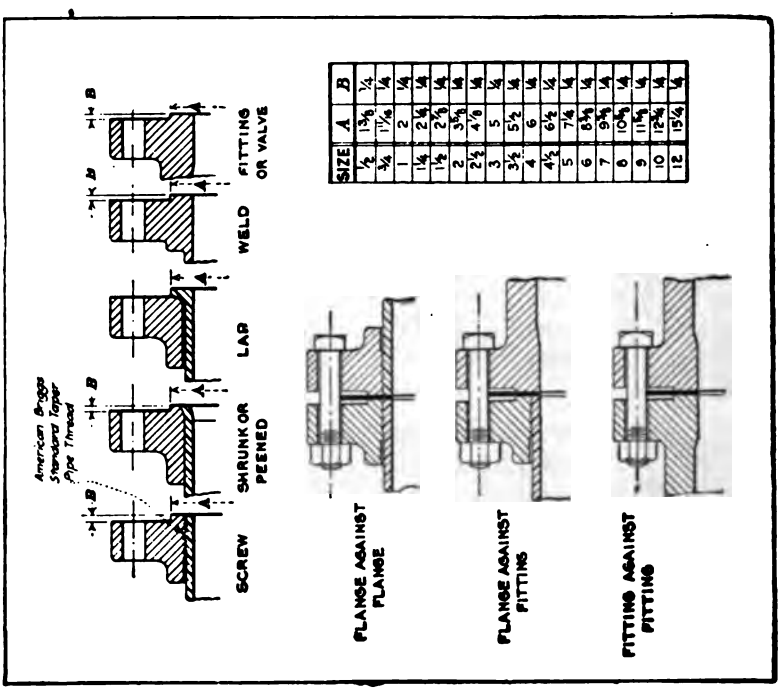
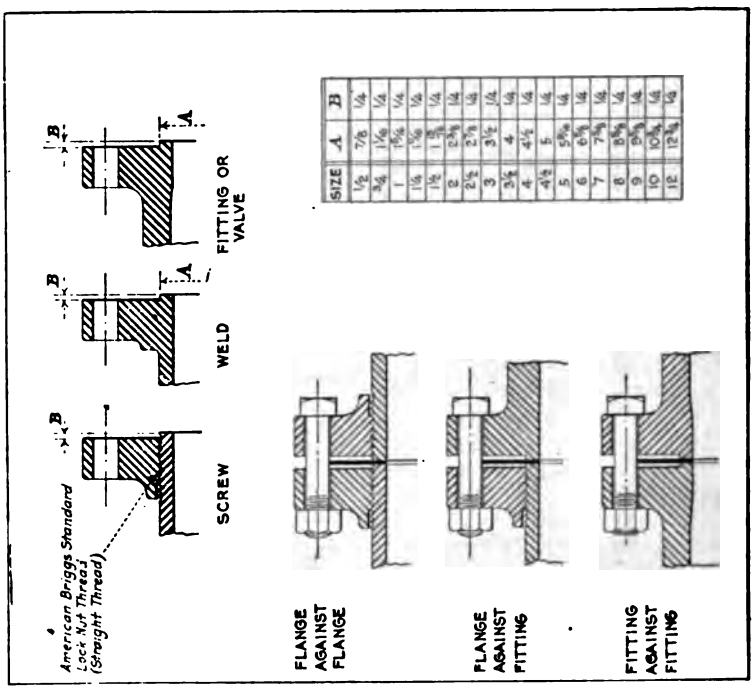


FIG. 1 HYDRAULIC AMERICAN STANDARD FLANGES AND FLANGED FITTINGS DIMENSIONED IN TABLES 2, 3 AND 4



SIZE	A	B
½	1 3/16	¼
¾	1 11/16	¼
1	2	¼
1¼	2 ¼	¼
1½	2 7/8	¼
2	3 5/8	¼
2½	4 1/8	¼
3	5	¼
3½	5½	¼
4	6	¼
4½	6½	¼
5	7¼	¼
6	8 5/8	¼
7	9 5/8	¼
8	10 5/8	¼
9	11 5/8	¼
10	12 5/8	¼
12	15¼	¼

FIG. 2 FLANGE JOINTS AND METHODS OF ATTACHING FLANGES TO PIPE, 800-LB. AND 1200-LB. HYDRAULIC AMERICAN STANDARD



SIZE	A	B
½	7/8	¼
¾	1 1/16	¼
1	1 5/16	¼
1¼	1 5/16	¼
1½	1 7/8	¼
2	2 3/8	¼
2½	2 7/8	¼
3	3½	¼
3½	4	¼
4	4½	¼
4½	5	¼
5	5 9/16	¼
6	6 9/16	¼
7	7 9/16	¼
8	8 9/16	¼
9	9 9/16	¼
10	10 9/16	¼
12	12 9/16	¼

FIG. 3 FLANGE JOINTS AND METHODS OF ATTACHING FLANGES TO PIPE, 3000-LB. HYDRAULIC AMERICAN STANDARD

No. 1655

PROPERTIES OF AIRPLANE FABRICS

By E. Dean Walen, Boston, Mass.
Junior Member of the Society

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The subject suggests that the investigation applies to a very limited class of fabrics, but many of the fundamentals discussed are applicable to the study of many of the fabrics used for more familiar purposes and of more general interest than airplane fabrics.

THE design of heavier-than-air machines during their early stages of development was arrived at by cut-and-try methods. The wings of such machines were covered with plain cotton fabric, much the same as an ordinary sheeting material, coated with a beeswax compound or some form of glue. The wing surfaces were then rubbed and polished to present a surface having a comparatively low skin friction. Such a covering was not very strong and sagged very materially when subjected to pressure and when exposed to weather.

2 As the application of science produced planes which were capable of much higher speeds, smaller wing surfaces, and a consequently increased loading per square foot of wing surface, it became necessary to cover them with a material having a high strength and a low weight.

3 It was generally known that flax spun into yarns and subsequently woven into fabrics produced a very tough material having little stretch and the property of withstanding shocks with very little permanent set.

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5 During the present crisis it became evident that the available supply of linen would not suffice the demands of the military programs of the countries at war, and it became necessary to find materials which could be used in place of the satisfactory linen.

6 As early as January 1916 the Bureau started investigating the possibilities of substituting cotton for linen airplane fabrics, and found that the general consensus of opinion among airplane manufacturers and investigators here and abroad was that the use of cotton fabric for wing coverings was out of the question, as many experiments had already been made to substantiate these opinions.

7 However, we were certain that not all the possibilities of structure of fabric had been considered, and we began an investigation to study the stresses in a fabric on a plane and to thoroughly determine by actual measurement the properties of the linen fabric and to incorporate the desirable properties of the linen in a cotton fabric suited for the purpose.

8 The difficulties experienced in the experiments on cotton fabrics previous to the time of our investigations were: (*a*) low strength per unit of weight; (*b*) low tearing resistance; (*c*) little shrinkage upon application of dope; (*d*) little tendency to retain what little shrinkage they had after doping.

9 It was not until March 18, 1917, that we were in a position to issue instructions covering the construction of cotton fabrics for the experimental fabrics which proved to be quite successful. These instructions were sent to the various fine-goods cotton mills and were supplemented by visits of our textile experts to the mills.

10 At the mills our textile men sat down with the practical men and evolved the present cotton airplane fabrics. At this point I wish to mention the name of Mr. Ricketson, agent of the Ponemah Mills, as he did much to make cotton fabrics a success.

11 The first fabrics of this series were received at the Bureau on or about the first of April 1917, and as the series progressed we suggested changes, and during the early part of May 1917 a fabric had successfully passed our laboratory standards. The next important problem was to determine the actual performance of these

fabrics. To this end samples were placed on Army planes at Langley Field and Navy planes at Pensacola during August 1917. Similar fabrics were later sent by the Signal Corps to the Canadian Aeroplane Company, of Toronto, Canada, and they were placed on planes the middle of October 1917.

12 The results of the service tests demonstrated that the fabrics were satisfactory and that service results could be reliably predicted in the laboratory. In view of this we felt justified in modifying the structure of these fabrics, and in coöperation with Mr. R. L. Kingston, then with the Curtiss Aeroplane Company, and with Mr. A. R. Pierce, of the Pierce Manufacturing Company, the present Grade A cotton fabric was evolved.

13 It was not until August that the military authorities were becoming concerned with the scarcity of linen, and on or about the 23d of August the Joint Army and Navy Aircraft Board called the Bureau into a conference regarding cotton fabrics for airplanes, and we were able to say with a great degree of certainty that we had a fabric ready for their needs.

14 On August 24, 1917, a conference held between the military authorities and representatives of the Bureau resulted in the Signal Corps Equipment Division ordering that the Bureau of Standards supply the necessary specifications covering the purchase of 500,000 yd. of airplane cotton fabric. The specifications were transmitted by the Bureau of Standards on September 5, 1917, covering the fabrics now known as Grade A and Grade B as used by the Signal Corps and Navy. A few days later the Bureau supplied the necessary information regarding the apparatus and methods of testing and inspection.

15 The Department of Agriculture was invited by this Bureau to assist in further development, and the experiments were started during September 1917, but because of some unfortunate circumstance we were unable to keep in touch with the work. During April 1918 the Signal Corps submitted samples which we understood to be the result of these investigations. They dealt with the use of the various cottons and the experiments were very valuable.

16 Recently the standard fabrics were submitted to the English airplane authorities and their comments were to the effect that the results of their tests were astonishingly successful. Since that time the English have adopted the standard Grade A fabric.

17 At the time we were making our field tests at Langley, the Italian Aviation Mission was there. One of their planes was covered

with a cotton fabric which they had used successfully on the battle front, and the members of that Mission offered the opinion that our fabrics were better than their own successful fabric. It is a peculiar thing that upon analysis this fabric differed but slightly from our own as far as thread count and yarn number were concerned. Here were two people working on the same problems, on opposite sides of the water and having no information regarding each other's work, and the results were practically the same.

18 It is necessary to determine the requirements which a material must satisfy, together with the properties of the material being substituted, before suitable substitutes can be found.

19 This discussion treats of the methods of determining the properties of textile materials from which may be determined their compliance with the requirements of airplane wing coverings.

METHOD OF COVERING AIRPLANE WINGS

20 It is thought advisable to discuss briefly the method of covering airplane wings in order that one may follow the discussion with more interest. The frame of an airplane wing is covered with a fabric according to one of the following methods: The fabric is sewed into a piece which is wide enough to cover, and is folded completely over and under, the wing frame. It is then tacked on the three open sides after being stretched just enough to take out the wrinkles. The raw edges of the fabric are then sewed together and the tacks removed. The other method consists in making of a pocket of fabric and slipping it over the frame. The open end is then tacked and sewed the same as in the previous case. The system of threads in the fabric may have the following two relations to the major and minor axes of the wing: The warp running from the "leading in" edge to the "trailing" edge, or parallel to the short or minor axis of the wing; or it may be put on such that the warp is at 45 deg. to the axis of the wing. The fabric is laced to the wing ribs at intervals of about six inches. After the fabric is on the frame, it is treated by means of a brush with a solution of cellulose acetate or nitrate with suitable stabilizers, etc., which is termed "dope." The dope has the property of producing a tight drumhead-like wing covering, which is often attributed to the shrinking of the fabric. It also serves to fill in the interstices of the fabric, making a surface which has a coefficient of friction to air approximately equal to that of plate glass. The doped wing fabric may be considered as a rectangular membrane fixed at two sides and supported on the other

two sides by the ribs of the frame, and that the wing is composed of many of these sections.

DETERMINATIONS OF THE PROPERTIES OF UNDOPED FABRICS

21 *Moisture.* The fact that all fibers, either animal or vegetable, absorb moisture in varying amounts is very well known. The effect of the moisture absorbed is little considered other than it affects the weight determinations.

22 For the purposes of this paper it is sufficient to know that the physical properties change in value with a change in the moisture content of the specimen, and that the changes of the properties of the various vegetable fibers are very much of the same order.

23 In view of this, it is necessary to either fix the moisture content of the materials being tested, or to expose them to a constant and known atmosphere. The ability of a material to absorb moisture is a distinct property of that material, and any method which fixes the moisture content does not allow of the accurate determination of the properties.

24 The moisture content of the test specimens is that absorbed by the material when exposed to an atmosphere of 65 per cent relative humidity at 21 deg. cent. until the moisture of the sample is in equilibrium with that of the atmosphere. This condition of atmosphere will be considered in this paper as a standard for the accurate determinations of the properties of textile materials. The amount of moisture is found by drying the sample to a constant weight in a ventilated drying oven maintained at a temperature of 110 deg. cent., and expressing the difference in weight from the conditioned weight in terms of the bone-dry weight. This is commonly termed "regain."

25 *Weight.* Pieces of 4 sq. in. are cut from various parts of the sample and weighed after exposure to the standard atmosphere, and the results expressed in terms of weight per unit of area. The commercial method of determining the weight per unit of area involves the measuring and weighing of an entire roll. A casual consideration of the two methods would lead to the conclusion that the latter procedure would give the more satisfactory result. However, the tension during measuring is not a constant or known amount. The variation in tension introduces an error, and the weights determined by this method usually run lighter than those determined from the small samples.

26 *Length of Yarn.* The length of a yarn is considered to be

that length when the yarn is straight and under no tension. The yarn is stressed in tension by equal increments of load and the stretch readings are taken at any particular load when the increments of elongation per unit of time are small. The stretch is plotted against the load. It has been found that after the fibers and the yarn have adjusted themselves the load-stretch curve follows a

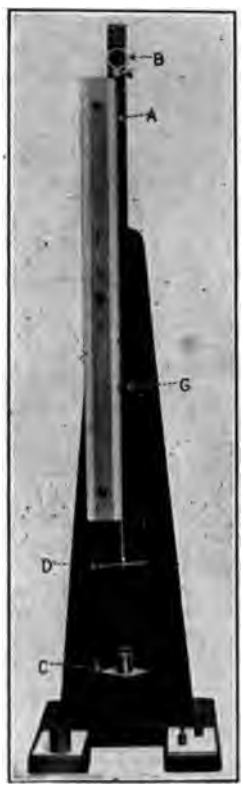

FIG. 1 INSTRUMENT FOR MEASURING THE LENGTH OF YARN

straight line. The straight-line portion of the curve is extended to intersect the zero-load coördinate, and this length taken to be the length of the yarn when straight and under no tension. The apparatus is shown in Fig. 1. The yarn *A* is clamped at one end in the clamp *B*. The other end supports the weight pan *C*. The yarn is prevented from untwisting by the cross-arm *D*. The clip *G* is an index mark to read the changes in length on the scale *F*.

27 *Crimp.* The crimp of a yarn is the increased length of the yarn taken from the fabric over the length of the fabric. The difference is caused by the interlacings of the yarns. This length of the yarn removed from the fabric is determined in the manner outlined above.

28 *Yarn Count.* The yarn count is a term used to designate the size of the yarn and is expressed in terms of length per unit of weight. For instance, a No. 1 cotton yarn has 840 yd. to 1 lb. It may be considered as a very approximate index to the diameter of the yarn.

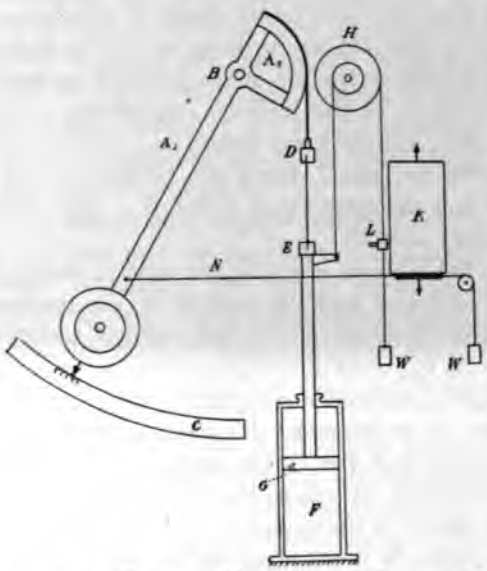

FIG. 2 INCLINATION-BALANCE MACHINE FOR TESTING TENSIBILITY PROPERTIES OF TEXTILE MATERIALS

29 *Thread Count.* The thread count is the number of yarns per inch of width of the fabric, and its determination needs no discussion.

30 *Twist of the Yarns.* This term is perfectly obvious and needs no discussion. It is determined by counting the turns necessary to untwist the yarn, and the result is expressed in terms of twist per unit of length of the yarn before untwisting.

31 *Tensibility Properties.* The tensibility properties of a textile material may be defined as the behavior of the material when subjected to tensile stresses acting parallel to and at the center

plane or line of the material. These may be divided into the following: (*a*) load-stretch relations; (*b*) tensile strength; (*c*) restitution and hysteresis.

32 The tensibility properties are determined in a testing machine of the inclination-balance type arranged to plot autographically the stretch against the load. A diagrammatic sketch of the apparatus is shown in Fig. 2. The inclination balance is represented by the pendulum arm A_1 and the sector arm A_2 which are rigidly connected and pivoted at the point B. The principle is one of balanced moments and its theory needs no discussion. The load applied at D is read on the scale C. The fabric clamp E, which may be termed a pulling clamp, is operated up or down at will by hydraulic pressure acting on the bottom or the top of the piston G confined in the cylinder F. The motion of the balance arm revolves the drum K by means of the thin, narrow brass ribbon N. The motion of the pulling clamp moves the pen L along the vertical axis of the drum by the ribbon M and the magnifying pulley H. The pen is arranged to make a dot every second.

33 Thin, flat ribbons of metal are used to reduce to a minimum the bending constraint and the friction of the motion-transmitting parts. The drum is set up in cone ball bearings, and by reason of this, together with its lightness and frictionless pen, the error in the reading of the weight is reduced to a negligible quantity. The pen-moving device need not be so delicately designed, as there is available ample power to operate, and the forces necessary to operate it have no effect on the readings, only in so far as they may produce hysteresis and backlash effects in the system.

34 The ribbon N is attached to the arm A_1 at a considerable distance from the pivot point B and the arm itself is operated through a very small angle. These simplify the spacing of the load coördinates on the chart, as they are equidistant along a horizontal line which is cut by the arm A_1. It is obvious that there must be a correction made for the motion of the clamp D. This correction is made by placing a comparatively rigid body such as a piece of steel in the clamps of the testing machine and moving down the lower clamp. The pen then traces the correction. During this operation the weight coördinates are marked off on the chart.

35 To test the apparatus for backlash and hysteresis the direction of the piston is reversed and the pen allowed to trace the motion of the top clamp. If there is no backlash, the two lines, up and down, will coincide with each other The effect of backlash and

hysteresis in the recording apparatus is very important in the determination of the restitution and hysteresis properties of the material being tested. It was found that the apparatus used was practically free from such effects. The calibration of the chart for stretch is made by allowing the top clamp *D* to remain stationary and moving the clamp *E* a definite distance, noting the motion of the pen. This type of testing apparatus gives fairly accurate results if operated at slow speeds, as the inertia effects of the pendulum arm are very pronounced at the higher speeds of operation.

36 The tensibility properties are determined in the following manner, which, it will be noticed, is a deviation from the usual method: Samples of fabric are cut 3 cm. wide by 25 cm. long. These are raveled to 2.5 cm. wide and allowed to condition. They are then placed in the clamps of the testing machine with 20 cm. between clamps and stressed by reason of their being stretched at the rate of 13 cm. per min.

37 The inclination-balance type of testing machine is calibrated under static conditions and operated when dynamics introduce a considerable error. Obviously the inertia effect of the pendulum arm varies with the type of the material being tested. It is necessary in investigational work to correct for this error, or to operate the machine at such a slow speed that the errors arising will be negligible.

38 The tensile strength and load-stretch relations are taken directly from the chart. The hysteresis and restitution properties are determined by stressing the fabric specimen to a certain load, and relieving the stress in the same manner as applying it. This may be repeated a number of times and the results taken as an index of the fatigue properties of the material.

39 *Tearing Resistance, Tensibility Method.* For this particular purpose the tearing resistance is determined in the following manner, which is a slight modification of the English method.

40 Specimens 25 cm. wide and 36 cm. long are clamped in the testing machine with 30 cm. between clamps. Slits are cut at the center and perpendicular to the line of pull, and the fabric is then stressed at the rate of 13 cm. per min. and the maximum load transmitted recorded. The length of the slit is plotted against the load recorded.

41 The maximum length of slit which may be used with this size of sample is determined by the proximity of the zone of stress about the tearing point to the edge of the sample. The area of this

zone is easily determined by drawing a series of lines parallel and perpendicular to the line of pull. These lines will be distorted in the zone of stress.

42 *Resistance to Uniformly Distributed Pressure.* The material is clamped over a rectangular container and subjected to air pressure. The apparatus is shown diagrammatically in Fig. 3.

43 The deflection of the center point of the fabric is plotted against the unit pressure under the fabric by means of an ordinary steam indicator. The shape of the deflected surface is determined

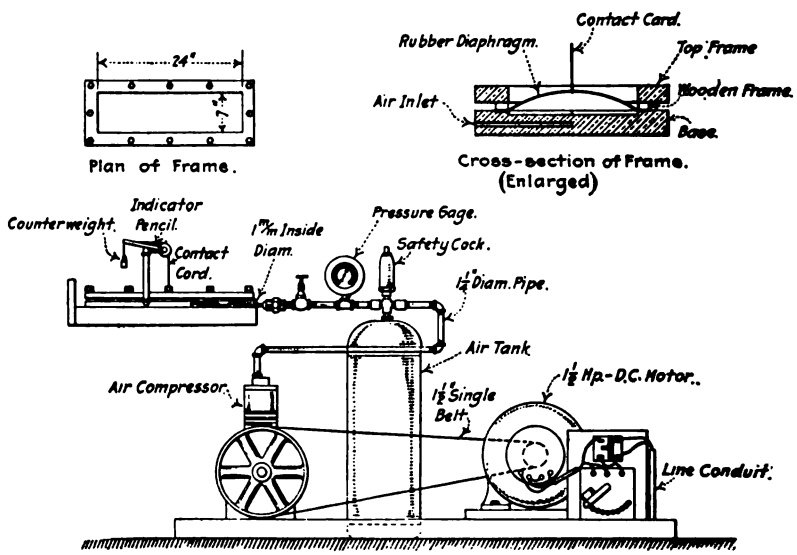

FIG. 3 APPARATUS FOR TESTING BURSTING STRENGTH OF CLOTH UNDER UNIFORMLY DISTRIBUTED PRESSURE

by measuring the vertical displacement of a series of rods placed at various points over the surface and free to move only in the vertical plane.

44 The rate of flow of air into the chamber under the fabric is very slow and is regulated by passing the air which is under a pressure of 10 kg. per sq. cm. through 110 cm. of 1-mm. tubing. A sheet of rubber dam is placed under the fabric to prevent air leakage. Considering these precautions, it is reasonable to assume that there is a very uniform distribution of pressure under the fabric. As there is practically a zero rate of flow of air into the indicator, it is reasonable to assume that there is no pressure drop in the connecting line.

45 In the surface formed by plotting the load-stretch and time relations of a fabric, there is a region where a change in the rate of load application produces only a slight change in the tensibility properties of the material. The rate of load application in this apparatus is adjusted by the definition of the pressure and dimensions of the capillary tube in such a manner that the variations in the load applications produce only a very slight difference in the recorded tensibility properties of the material.

46 *Bursting-Tear Test.* The procedure is similar to that followed in the determination of the resistance to uniformly distributed pressure, excepting that slits are cut in the fabric at various points and the pressure necessary to start the tear is recorded together with the deflection at the time of tear.

DETERMINATIONS OF PROPERTIES OF DOPED FABRICS

47 *Preparation of Samples.* The fabrics were stretched and tacked on frames under a tension of 80 gr. per cm. of width and doped in a room maintained at approximately 65 per cent relative humidity at 21 deg. cent. The frames were 30 cm. by 30 cm. (inside dimensions) for the preparation of specimens for the determination of tensibility properties and 18 cm. × 61 cm. for the determination of resistance to pressure. The properties of doped fabrics were determined in the same manner as those of the undoped fabric, with the exception that the tensibility specimens were cut to 2.5 cm. width parallel to the line of threads.

48 *Properties of Dope Films.* Films of dope were made by painting the dope on glass plates and the films were subsequently peeled off and determinations made of tensibility and resistance to pressure.

49 *Exposure Tests.* The fabrics after tacking on frames and doping were placed on the roof and determinations made periodically of their physical properties.

VALUE OF TESTS

50 The determinations of weight, yarn size, crimp, thread count and twist are made primarily to explain difference in properties, and more particularly to interpret properties in terms which readily adapt themselves to manufacturers' conditions. The effect of these values on properties will be indicated to give the reader a general conception of these effects.

51 The question of identification of fiber has not been discussed,

but the effect of the different grades of fibers is noticeable when passing from one distinct staple to another. Up to the present time there have been no satisfactory methods of grading cotton other than those which depend almost entirely upon the judgment of the particular person. The choice of fiber should be left, within reasonable limits, to the manufacturer, for the manufacture of textiles to have definite properties is not a mathematically calculable process, and the laboratory can only hope to determine and indicate in a general way the effect of the many variables.

52 The relations between yarn number, twist, threads per inch, weight, and weave are apparently those which explain the differences in the physical properties of the several fabrics, and further serve as the most valuable manner of designation of the fabrics.

53 The ability of a fabric to "take the dope" is influenced almost entirely by the relations between yarn number, twist, threads per inch, weight and weave, and they are practically the only measure of such a property. The functions of the dope are to produce a reasonably tight covering, to protect the fibers from the influence of the atmospheric conditions and to produce a windtight surface. In order to perform these functions most advantageously it is necessary that one or two coats of dope penetrate the fabric enough to thoroughly protect the fibers and to serve as a necessary bond for the subsequent coats, which should be more of the nature of a surface coating. It has been thought that a yarn made absorbent by chemical treatment is more desirable, but when it is considered that such an extreme penetration of the dope will produce a brittle fabric, the value of such a treatment is practically nothing.

54 Provided a yarn may be made which has little hysteresis effect, it is only necessary that a thin film of dope surround the yarn. This condition is attained only at the expense of overtwisting, and its object is therefore defeated by a subsequent loss of strength of the fabric. From this it is readily seen that the dope serves a secondary purpose of supplying an additional bond between the fibers. The most advantageous condition of dope penetration into the yarn is obtained by twist regulation.

55 *Crimp.* The crimp of the yarn is the largest determining factor of the load-stretch relations of a fabric, particularly at the lower loads or under conditions of normal flight. This will be discussed under tensibility properties.

56 *Tensibility Properties.* The value of tensile strength as a measure of the quality of an ordinary textile material has long been

realized, and it was largely the fact that this value was solely considered, which misled investigators of cotton airplane fabrics.

57 An airplane wing covering, for purposes of this discussion, may be considered as a flat, rectangular sheet supported on four sides and subjected to pressure which may be considered as uniformly distributed over an area defined by the width of the rib spacing in one direction and relatively small distance in the other direction. The stress in the material of the section being considered is a function of the reciprocal of the radius of curvature plus a factor involving what is usually termed as an axial tension load. The curvature at any given pressure is determined by the load-stretch relations of the material, and although the load-stretch diagram does not consider the effect of axial loading, it does serve as a very valuable index to relative factors of safety of the various materials. The wing covering must be airtight in order that the pressure may not build up on one fabric alone and that flight efficiencies may not be lowered. The material will remain windtight so long as the dope film is not ruptured or deteriorated.

58 The life of a fabric may be considered to be dependent upon the life of the dope. The dope may be caused to become deteriorated either by repeatedly exceeding its elastic limit or by exposing it to deteriorating rays of light. The latter condition may be reduced to a minimum by coating the material with pigmented varnish or dope which is opaque to the deteriorating portion of the spectrum. (This development may be attributed to an English investigator.)

59 The shape of the tensibility curves of the doped fabric serves as a valuable index as to whether the elastic limit of the dope will become exceeded under conditions of flight.

60 The ability of a fabric to shrink depends largely upon its load-stretch relations. The term shrinkage has been applied to refer to fabric tautness and leads to confusion as to the nature of the tightening. It has been observed that the fabrics having the least stretch at the low loads are tightest after doping, and that a plain-weave fabric is tighter than a fabric woven with fewer intersections and having less stretch. The fabric tautness is dependent largely upon the support which the fabric lends to the dope and the completeness with which the dope binds the yarns together in their crimped condition, and is dependent only slightly on film shrinkage.

61 The necessity of fabric tautness is believed to be largely dependent upon the psychology of the flyer, but, with the present

dopes, fabric tightness is almost synonymous with life of the dope or fabric.

62 It is believed that the fatigue properties of a fabric may be related rather definitely to the shape and area of the hysteresis loop. Although this phase of the investigation is not entirely complete, the area of the hysteresis loop has been used to predict the fatigue properties of the materials with a large degree of success.

63 The relative recoverable stretch of an airplane wing covering is quite readily indicated from an examination of the hysteresis loops of the load-stretch diagrams. It was not intended to convey the idea that all degrees of wing-covering looseness were equally desir-

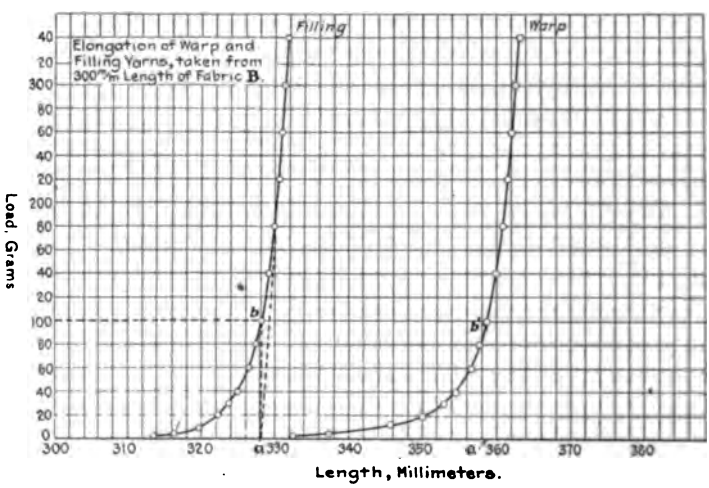

FIG. 4 TYPICAL SET OF CRIMP OR YARN-LENGTH READINGS

able, and in the absence of exact data on the effect of fabric looseness on lift and drift, the allowable lack of recoverable stretch must be left to the judgment of the investigator.

64 The effect of the amplitude of the vibrations of a wing covering is, after a few flights, determined by the recoverable stretch of the material, and here again this phase of the investigation is not complete and the magnitude of this property must be left to the judgment of the investigator.

65 *Tear Resistance, Tensibility Method.* This method of determining tear resistance has been considered less applicable to wing-covering materials, as the value of the load-stretch relations is not fully realized, and has been superseded by the bursting-tear method.

The method may be used, however, in cases where the samples are too small for bursting tear and where such apparatus is not readily obtainable.

66 *Resistance to Uniformly Distributed Pressure.* As has been already pointed out, the stresses in an airplane-covering material are a function of the curvature of the material at any pressure. It has been observed that the tensibility curve obtained by plotting calculated surface tension against stretch of the material during the application of pressure does not agree with the load-stretch diagram.

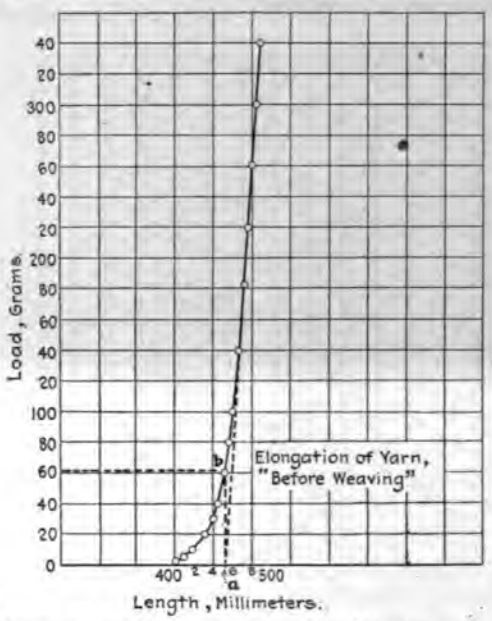

FIG. 5 CRIMP OF AN UNWOVEN YARN OF COARSE AND MULTIPLE STRUCTURE

The difference is probably due to the initial stress in the doped fabric and to the fact that the end and side effects of the tension strips are not present in the pressure test.

67 The test does not include the effect of tensions such as would result from wing deflections, but does serve as a more valuable index to factors of safety than the conventional tensile test. From the pressure-deflection curves it is easier to visualize the relative effect of wing deflection. The true conditions of flight are not duplicated, but the effects of the two systems of yarns are integrated and the results are less deceptive than those obtained from tensile tests.

68 *Bursting-Tear Test.* This test, like the bursting test, is a much better index to relative factors of safety than tension-tear tests. Questions of fabric reinforcement and balance of fabric are readily solved by a careful interpretation of the results obtained from such a test.

RESULTS OF TESTS

69 It is proposed to give typical examples of tests performed on satisfactory and unsatisfactory fabrics in order that the value of the tests may be more readily realized.

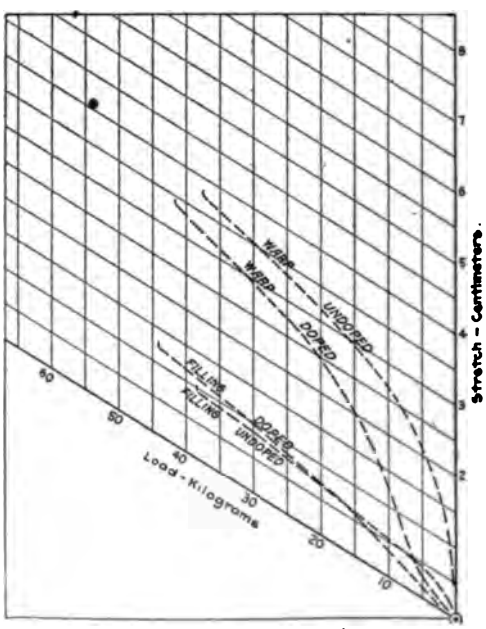

FIG. 6 LOAD–STRETCH RELATIONS OF STANDARD ENGLISH GRADE A AIRPLANE LINEN

70 *Length of Yarn and Crimp.* A typical set of crimp or yarn-length readings is shown in Fig. 4. It will be noted that the load-stretch relations follow a straight-line ratio after a particular tension is reached. It is assumed that the yarn has adjusted itself after this point is reached and that if it were not crimped the relations would exist below this point.

71 Fig. 5 shows the crimp of an unwoven yarn of coarse and multiple structure. Consequently the yarn and fibers are in more

or less of a crimped condition, as is shown by the lower part of the curve.

72 *Tensibility Properties.* The load-stretch relations of a standard English Grade A airplane linen are shown in Fig. 6. It will be noted that the doped-filling curve is practically a straight line. The doped-warp curve shows a distinct yield point, as is indicated by the reversal of the curvature of the diagram.

73 Fig. 7 represents the load-stretch relations of a standard A grade cotton fabric, which curve, it will be observed, is very similar to that of the linen fabric.

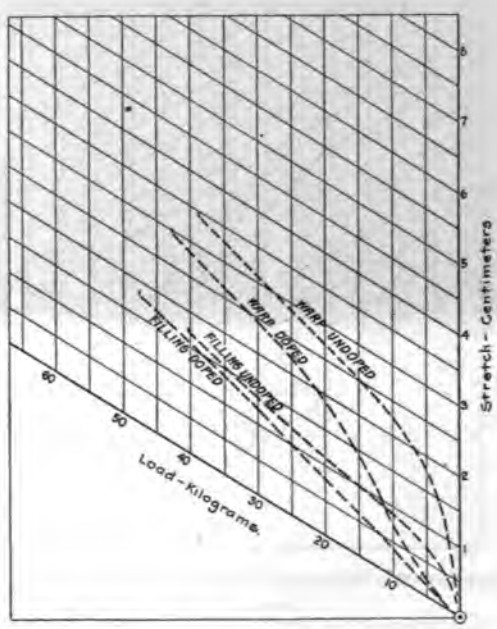

FIG. 7 LOAD–STRETCH RELATIONS OF STANDARD A GRADE COTTON FABRIC

74 The load-stretch diagram of a fabric may be divided into three parts according to the preponderating influences in these particular portions: (*a*) crimp; (*b*) crimp and yarn; (*c*) crimped-yarn characteristics. Referring to the warp load-stretch diagram of the cotton fabric, Fig. 7, the part of the curve extending to approximately 3 kg. is influenced almost entirely by crimp; the curve from 3 to 10 kg. by yarn and crimp; the curve from this point on shows the characteristics of the yarn in its crimped condition.

75 This analysis suggests the particular part of the manufacturing process which should be varied to produce the desired shape of curve. The part of the curve below 10 kg. may be varied by changing the weave structure, stiffness of the yarn, and more particularly tension, on the yarns during weaving. The sum of the respective stretches of the warp and filling at this point is determined by the weave structure, and the relative magnitudes of the respective stretches of the warp and filling are determined by loom tensions.

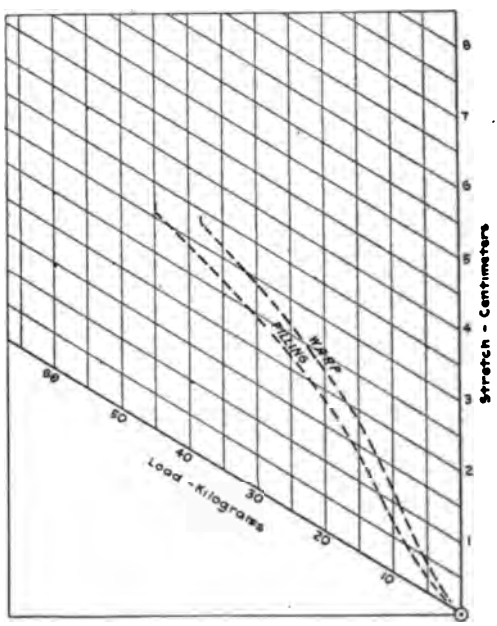

FIG. 8 LOAD–STRETCH DIAGRAM OF A 3/80'S UNMERCERIZED FABRIC DOPED

76 Fig. 8 represents the load-stretch diagram of a 3/80's unmercerized fabric doped. Both the warp and filling show a dope yield point between 5 and 10 kg., as is represented by the reversal of the curvature of the diagram.

77 The same construction of fabric made of mercerized yarn is represented by the load-stretch diagram, Fig. 9. The filling diagram does not show a reversal of curvature and the elastic limit of the dope will not be exceeded under normal conditions of flight. Service tests on these latter two fabrics showed that the unmercerized fabric became somewhat mushy after a short period while the mer-

cerized-yarn fabric stood up very well. Similar tests on fabrics of various load-stretch diagrams showed that the fabrics whose dope-filling load-stretch diagrams were practically straight lines stood up exceptionally well.

78 The maintenance of the strength and the tautness of the cotton fabrics is dependent upon the completeness with which the dope protects the fabric and the completeness with which the dope is protected from deteriorating influences such as light and weather.

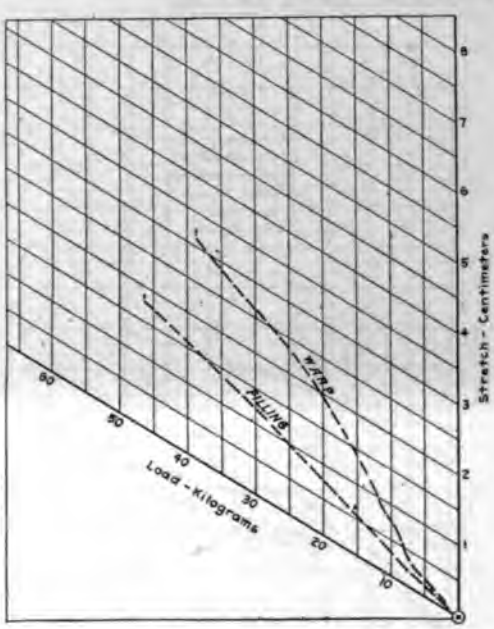

FIG. 9 LOAD–STRETCH DIAGRAM OF A 3/80'S MERCERIZED YARN

79 The dope penetration of the 3/80's fabric, 70 square, plain weave, is excessive. The dope penetration of the 2/60's standard fabric is slightly more than that of the standard linen fabric. Excessive penetration of the dope reduces the tear resistance materially. If the standard 2/60's fabric is woven in a 2 × 2 basket, the dope penetration is such as to cause an extremely low tear resistance. The small crimp in such a fabric makes it dope up very tightly.

80 *Bursting Test.* The curves, Fig. 10, represent the pressure-deflection properties of the center point of the fabric when subjected to air pressure, as previously described. The deflection at any load

of the fabric undoped is larger than that of the dope film. The deflection of the doped fabric is less than the deflection of either the fabric or the film. This further substantiates the theory that tautness is produced by the dope constraining the yarns in their crimped condition, and that in the standard fabrics the elastic limit of the dope is not exceeded. It will be observed that the cotton fabric is capable of resisting more pressure than the linen, and it will have, therefore, a higher factor of safety. The fabric tautness is practically the same as that of the linen.

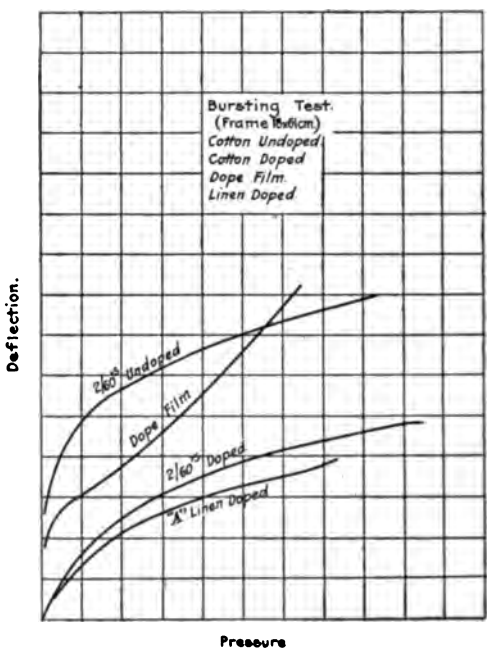

FIG. 10 DEFLECTION OF CENTER POINT OF FABRIC WHEN SUBJECTED TO AIR PRESSURE

81 *Tear Resistance.* From an examination of the distortion of the lines about a tear, it is concluded that the tear resistance is a function of the strength of the individual yarns and the number being stressed. The number of yarns being stressed is dependent upon the load-stretch relations of the fabric and the weave structure. To illustrate the effect of doping and weave structure on the tear resistance, let us consider two fabrics: (*a*) Standard 2/60's mercerized, 80 square, plain weave; (*b*) 2/60's mercerized yarn, 80 square,

2 × 2 basket. The tear resistance of the 2 × 2 basket is greater than the plain-weave fabric in the undoped condition.

82 The tear resistance of the 2 × 2 basket is less than the plain-weave fabric in the doped condition. The addition of plastics to the dope or the prevention of extreme dope penetration in the 2 × 2 basket will increase its tear resistance very materially. The reasons for these differences in tear resistance may be readily conceived from a consideration of the foregoing discussion.

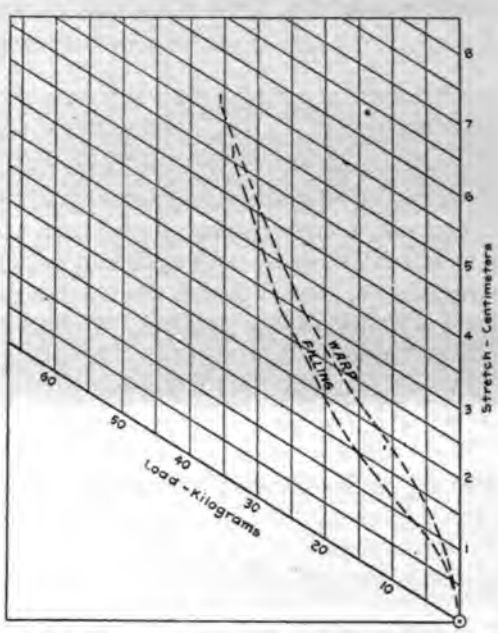

FIG. 11 LOAD-STRETCH DIAGRAM OF UNDOPED SILK FABRIC

83 *Silk.* The strength per unit weight of the silk fabrics has suggested an interesting study of its adaptability to airplane wing coverings. Fig. 11 represents the load-stretch diagram of an undoped silk fabric made from a Chinese steam filature silk and is representative of all silk fabrics made from what may be termed line silk. The curve shows a radical yield point and excessive stretch and therefore is not a logical airplane-wing covering material. It also indicates extremely inelastic properties, which hysteresis determinations substantiate.

84 The silk schappe fabrics do not indicate a yield point, but do in most cases have excessive stretch. They would, however, make

very good wing coverings. Doped silk fabrics are caused to become loose upon exposure to damp weather, and in many cases a rot develops on the inside of the yarn. Both of these objectionable features will probably be overcome in the near future.

85 Further experiments are being conducted to determine the properties of airplane fabrics which have to do with the calculation of the exact performance of any fabric under any assumed condition of flight, which will include the effects of various rib spacings, wing deflections, vibrations, and the effects of various fabric structures.

DISCUSSION

Wm. T. Magruder (written). It is requested that the author add to his interesting paper the weights, either in ounces per square yard or in the equivalent metric units, of the linen and of the two cotton fabrics to which he refers, both with and without dope, and their tensile strengths per inch of width when subjected to a direct pull, which is the more usual way of testing the strength of fabrics.

It is suggested that similar tests be made of sheet-metal fabrics, such as some of the various steels, bronzes, and aluminum alloys, to determine their relative weights and strengths and their desirability for this use. Their stiffness, resistance to being torn, ease of protection from rusting, their not being affected by the sun as are airplane fabrics, and the ease and cheapness with which they can be laid and repaired by the electric welding process, are worthy of consideration.

P. J. Freeman (written). The effect of dope on the resistance to tearing seems to me to be the most important feature in connection with the testing of an airplane fabric. That is, the untreated cloth and the dope may be satisfactory, yet when combined the cloth tears readily. Would a method similar to tearing a strip of cloth about 1 in. wide from a large sheet of doped fabric be of value?

F. J. Hoxie (written). Soon after war was declared, the Warwick Mills and Wellington, Sears & Co., their sales agents, purchased apparatus and started two laboratories for the study of balloon and airplane cloth. The best of foreign yarns and cotton was imported. American yarns were purchased from spinners of highest repute and experimental yarns were spun at their own spinning mill. Many ex-

perimental weaves were tried, the object being to find the strongest cloth with the least possible weight and at the same time with greatest resistance to tearing. It is not necessary to go into the details of this work, but a few of the more important fundamental principles investigated upon which depends the manufacturing of a strong, light cloth of high tearing resistance, and doping the same to retain these desirable qualities, are of interest.

Fig. 12 is a micrograph showing a section across the filling and along the warp of the cloth now in use. Fig. 13 similarly shows a section of a cloth commonly known to weavers as a 3 × 3 basket

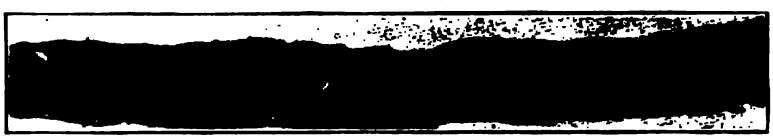

FIG. 12 ENLARGED SECTION OF COTTON CLOTH USED ON GOVERNMENT AIRPLANES

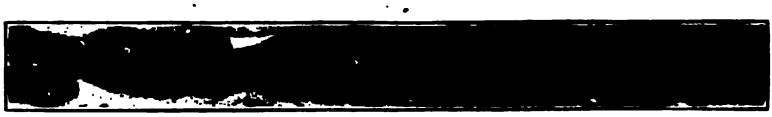

FIG. 13 ENLARGED SECTION OF 3 × 3 BASKET-WEAVE CLOTH

FIG. 14 ENLARGED SECTION OF 5 × 5 BASKET-WEAVE CLOTH

weave and Fig. 14 one of a 5 × 5 basket weave. In order to make it clear to those unfamiliar with the technicalities of weaving how these so-called basket cloths are constructed, the 5 × 5 basket weave is shown in Fig. 15 considerably magnified.

Airplane cloth is an unfamiliar problem to weavers. It is to be used as a structural material and therefore can be judged most logically by mechanical principles commonly used by engineers in the design of bridges and other structures. So considered, it is to be expected that the straighter the tension members the greater the strength, other things being equal. It will be noted that as the number of threads grouped increases the straighter they are; therefore, it is to be expected that the strength will increase with the number of

threads in a group and with their straightness. When tested on the bursting machine, as described by Mr. Walen, using square specimens 7 in. on the side, this ratio between strength and straightness is found to hold very exactly. When tests are made on long, narrow strips on cloth-testing machines in common use and also on long, narrow specimens in the bursting machine, the looseness of the yarn in the direction opposite to the stress allows it to become nearly straight when it breaks, however crooked it is in the cloth.

The curves in Fig. 16 show the actual results on the bursting machine with specimens 7 in. square. The actual recorded pressures

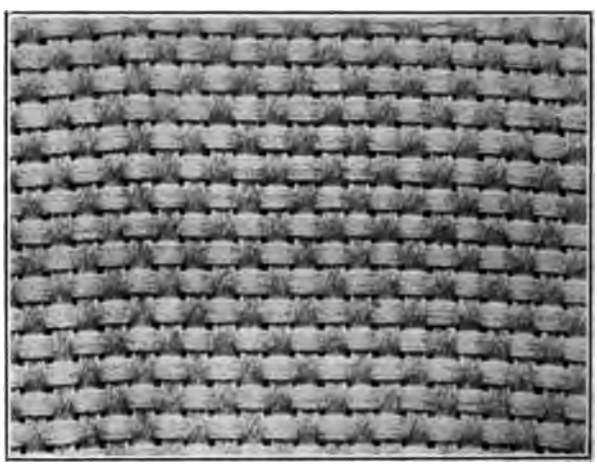

FIG. 15 5 × 5 BASKET-WEAVE CLOTH MADE OF 80'S THREE-PLY BLEACHED AND MERCERIZED YARN AND WOVEN 108 THREADS OF WARP AND 105 THREADS OF FILLING TO THE INCH; WEIGHT, 5¾ OZ. PER SQ. YD.

have been reduced by the ratio of the weights of the cloth, so that the results will be directly comparable assuming that the strength is in direct proportion to the weight.

The resistance to tearing shown by the basket weave is twice that of the plain weave, probably from two or more causes: first, in tearing more threads are stressed at once; second, the threads not being bent at such sharp angles by those crossing them, are freer to move and can therefore slide together, still further increasing the number stressed. It is also probable that there is less cutting action of the threads upon those crossing them after the manner commonly employed in breaking stout string with the fingers by causing the string to cut itself in two.

In the doping the utmost care must be used to regulate the bond between the cotton and the dope. This can be done to some extent but with somewhat eccentric results by controlling the moisture and temperature of the air in the doping room. The eccentricity is the result of the varying relative humidity at the surface of the cloth caused by the changing of the temperature of the cloth by the evaporation of the solvent. We have found that this control is best obtained by use of a moderately volatile material such as kerosene on the cloth which regularly controls the penetration, thus maintaining the high tear resistance of the undoped cloth and also very much improving and regulating its tautness. The action of this material in controlling the penetration of the dope is independent of the absorp-

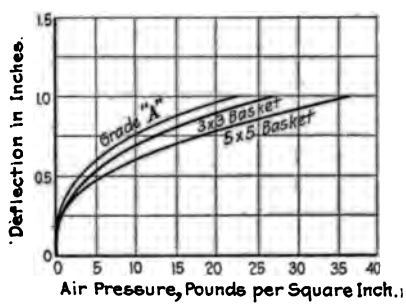

Fig. 16 Curves Showing Relation Between Deflection and Bursting Pressure of Airplane Cloth in Use at Present and Basket-Woven Cloth. Specimens 7 In. Square

tive qualities of the yarn, showing equally good results on unbleached or bleached cotton.

Tear tests were made on a horizontal testing machine by cutting the specimens 3 in. wide and placing them in 3-in. jaws with 1 in. of cloth between the jaws at the front of the machine and 3 in. between them at the back. With this arrangement a force of 10 lb. was required to tear the present airplane cloth. A force of 15 lb. was required to tear the 3 × 3 basket cloth and 25 lb. to tear the 5 × 5 basket cloth. When the 5 × 5 basket cloth is doped in an atmosphere of 30 per cent relative humidity without controlling medium the tear is reduced to 10 lb. and that of a plain weave in about the same proportion. With this cloth treated to prevent excessive absorption of the dope the tear is not materially reduced. The 5 × 5 basket cloth experimented upon is about 30 per cent heavier and the 3 × 3 about 25 per cent heavier than the plain airplane cloth at present in use.

From this investigation thus far it is concluded that the 5 × 5 basket-weave cloth has about 50 per cent higher bursting strength with a deflection at the same pressure about 25 per cent less and 100 per cent higher resistance to tearing than the cloths now being used, and by the use of a suitable control of penetration, or dam, as it has been called, the tear resistance of any cloth as well as its tautness, can be much more uniformly regulated than is the case with present practice.

Marcum D. Whitman wrote briefly concerning the pioneer work of the William Whitman Co., Inc., in the substitution of cotton for linen in certain materials. They began their experiments long before cotton fabrics were generally adopted and before any shortage of linen became apparent, and felt that they had demonstrated that aeroplane-wing covering material as reliable as linen could be made from cotton.

Dr. Arnold. In regard to Professor Magrader's comment, the following table compares linen with cotton in the dyed condition. Particular attention is called to the bursting pressure per unit of weight.

[illegible]	[illegible]	[illegible]	Bursting	[illegible]	Burst Tear	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

The work of Mr. Hoxie has been most interesting, and the theory of the basket fabric is good. Mr. Hoxie neglected to state that Wellington, Sears & Co. began their experiments on the basket fabric only after being urged to do so by the Bureau of Standards.

It is very unfair to compare the crimp of the warp of the Grade A fabric, Fig. 12, with either the warp or filling of the basket fabric, as the warp of the Grade A carries little or no stress, as it is parallel to the long axis of a wing bay.

It is not entirely true that the greatest strength is developed by the straighter yarns, other things being equal. This is true only when the yarns are of maximum strength, as the interlacing will increase fiber bond, and in many cases a stronger fabric may be developed by using a plain weave. There is no doubt that the yarn used by Mr. Hoxie is best when used with as few interlacings as possible.

The use of a square bursting apparatus is not favorable to any fabric which has not a balanced stretch, and is not a very close approximation to the actual use of the fabric. A square frame allows the warp and filling of a balanced fabric each to carry one-half the load. This might be thought to test the behavior of the fabric when placed on the bias; but it does not, for the span of any one thread should be 7 in. $\times \sqrt{2}$, which would naturally alter the deflection and surface tension for any given pressure. The curvatures of a square deflected surface are materially different from those of a rectangular surface.

Reducing the result of tests by mathematical methods is an entirely different thing from reducing the weight of the fabric, and a conclusion derived from mathematical reduction may be misleading, as it does not consider the practicability of actually making such a fabric.

Our solution of the problem of obtaining the maximum utility of a fabric is to make the filling of 2/60's yarn, and the warp of single 60's, to weigh 3.5 oz. per sq. yd. The bursting pressure for this fabric is much greater than that of the Grade A linen, and the effective tear resistance is approximately 50 per cent greater, as determined in the "slip stream."

No. 1656

INDUSTRIAL POWER PROBLEMS

By W. F. Uhl, Boston, Mass.
Member of the Society

In order to determine the best source of power for an industry, where there is a choice, it is generally advisable to consider the reliability of the source primarily and its cost only as a secondary matter. Fuel saving was formerly considered along with the cost of power, but must now be treated as one of the factors affecting reliability of power and from the broad economical standpoint of fuel conservation.

It would generally be good policy to purchase power where this source is available, even if the cost is somewhat higher than would be the case with power produced by the industry, providing always that the purchased power is reliable.

Many industries are confronted with situations where the determination of relative reliability and cost are somewhat complex. Such a situation occurs where an industry owns or could develop a water power or where there is a demand for low-pressure steam and hot water which could be obtained as a by-product from a steam-power plant operated by the industry or where the steam power from such a plant would be a by-product in the production of low-pressure steam and hot water. Other situations are combinations of water power with supplementary power of some kind, where there is no demand for low-pressure steam, or where a small water power is supplementary to other sources of power. In the latter case the problem usually is to make the best use of the water power.

A number of fairly common situations have been defined in this paper and some approximate data are given to assist in the determination of relative reliability and cost in each case.

THE two principal sources of power for industrial purposes at this time are steam and water-power plants owned and operated by the industry, the so-called isolated plant; and the purchased electric current from the public-service power companies, the so-called central plant or system.

2 Where both steam and water power are used by either the isolated or central plant, the steam plant is often supplementary to the water power, although the reverse is also often the case, particularly in the isolated plant.

3 The principal points which must be considered when provisions are to be made for a power supply for an industrial plant

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are reliability and cost. The relative importance of these two items is in the order stated and for many plants the last item is comparatively unimportant.

4 Conservation of fuel, which until recently received consideration only as an element in the cost of power, is now an important factor also from the standpoint of reliability. Within the last year it has become apparent that the important thing is to have power, no matter from what source; and within very wide limits, no matter at what cost.

5 Unfortunately, it is much more difficult to determine which of several sources of power is the more reliable than to determine which is the cheapest, and it is probably for this reason that the question of reliability is often largely disregarded. If it could be reduced to definite figures, as the question of cost can be to a fairly satisfactory extent, it would without doubt be more thoroughly considered. Although general claims are sometimes made that the central plant is more reliable than the isolated plant, or vice versa; and similar claims are made as to the cost of power and lately as to their relation to the conservation of fuel, such claims do not appeal to the engineer conversant with these matters. He knows that at best they could hold true only within certain limits. As with so many other engineering problems, very few cases are alike, although there may be much similarity.

RELIABILITY

6 The proportionate cost of power to the total cost of the commodity produced for sale in most industrial plants is below 5 per cent; and, as already stated, reliability is of much greater importance than cost when considering the supply of power for such plants. An analysis of any power situation should therefore first consider the relative reliability of the various sources of power.

7 When considering reliability our first thought is generally related to shutdowns. The loss due to complete failure of power supply, when translated into dollars per hour or other time interval, is one of the uncertain quantities which make the question of reliability so difficult of solution. This loss is subject to determination if we make certain assumptions. For instance, if we have a plant that operates continuously, the loss due to a shutdown can be directly calculated in terms of average profit, plus idle-labor cost, plus spoiled stock in process, plus fixed charges. As most plants do not operate continuously, the time lost during shutdowns can generally be made up, at least to some extent, and the loss may be

reduced to the cost of labor only if the nature of the industry is such that stock in process will not spoil.

8 Poor speed and voltage regulation are causes of unreliability of power supply, which, since they are not so apparent as complete shutdowns, do not often receive due consideration, yet may result in important losses. Such losses are subject to determination in terms of reduction of output and poor quality of product.

RELATIVE RELIABILITY

9 Relative reliability is also somewhat indeterminate, but there are certain factors which have an important bearing on the subject. Ignoring the question of shortage of fuel, which it is hoped is only a temporary problem, and assuming equal reliability of plant, steam power is more reliable than water power, excepting in certain noteworthy cases. The chief sources of unreliability of water powers are variability of stream flow, ice troubles and floods.

10 Storage and development to use only the minimum flow, location as to climate, good design or favorable natural conditions other than climate and high heads, are factors which make the exceptions where water power is equally as reliable as steam power. In most cases water power must be supplemented to some extent by auxiliary steam or other source of power to make it equally as reliable as steam power alone.

11 Where the water-power plant is located at some distance from the industry which uses it, the necessary transmission of the power introduces another factor which makes it less reliable than the power obtained from the steam plant located at the industry.

12 Relative reliability as between the power obtained from the isolated plant and that obtained from a central plant or system depends upon the following principal factors: (1) Size of plant; (2) reserve capacity; (3) quality; (4) transmission.

13 *Size of Plant.* Unless the central plant is several times the size of an isolated plant of 500 kw. or greater capacity, it would be unusual to obtain greater reliability because of the factors which are generally considered as having a tendency to promote reliability merely on account of size. Such factors are design, quality of supervision, equipment, location, etc.

14 The average 1000-kw. isolated plant does not receive the attention in design, supervision, etc., that the average 10,000-kw. plant does, but it would be a mistake to assume from this that all small plants are poorly designed or supervised or that there are no 10,000-kw. plants which are not poorly designed or supervised.

15 However, under average conditions, where the central plant is comparatively large, superior reliability as to plant and operation may be assumed, as it is reasonable to expect that everything will be done in the way of installing proper equipment and obtaining skilled and specialized supervision and management which has no other duties to perform than those of producing power. At least, these are the things which one should expect to find in connection with a large plant, and it should be fairly easy to determine whether they exist.

16 *Reserve Capacity.* Reserve capacity has an important bearing on the question of reliability. An isolated plant can be said to be thoroughly reliable if it has an installation such that any one unit, as, for instance, prime mover, boiler, pump, etc., can be idle and the plant still carry the entire load. Such a plant might consist of two complete power units, each capable of carrying the entire load, and a spare boiler, or three power units, any two of which could carry the entire load if operated at some overload, and a spare boiler.

17 A central plant to have equal reliability as to reserve capacity must be able to carry its peak load at some overload on about 75 per cent of its rated capacity, depending to some extent on the number and size of units installed. If the isolated plant operates only nine or ten hours a day and is usually shut down over Sunday, it can get along with less reserve capacity than the central plant operating continuously, as there are more opportunities to make extensive examinations and repairs.

18 *Quality.* When speaking of quality of power, we refer to those characteristics which affect the speed and efficiency of the motors, such as speed variation and voltage regulation. These characteristics of power also affect both the quality and quantity of the product of many industries.

19 In some industries the uniformity of the product is not affected by speed variation, or it may be unimportant. The effect on the *quantity* of product, however, is more important than is usually realized.

20 The efficiency of motors as affected by low voltage is relatively unimportant, but should also receive consideration, especially if the motors are fully loaded.

21 Speed variation is apt to be less in the average central plant, due to the larger amount of connected load and its diversity. Motors which are large compared with the total load and which carry a

variable load are a source of poor speed regulation, whether connected to the isolated or the central plant. Better voltage regulation is usually obtained from the isolated plant because of the absence of transmission lines.

22 *Transmission.* The one great weakness of central-plant power service is the necessary transmission. Even if the transmission is of the best and thoroughly protected by placing it in underground conduits or otherwise, it is always a source of possible trouble with which the isolated plant does not have to contend.

23 Under favorable conditions this element of unreliability may be almost negligible, but more often, especially with long overhead transmission, it is the greatest source of shutdowns and poor voltage regulation in the present state of the art of power generation and use. It affects most those industries which are liable to have stock in process spoiled, due to shutdowns, or which produce a poorer grade of material on account of ununiformity.

24 More critical selection of loads connected, building of transmission lines and substations with greater factors of safety, less overloading of lines and advance in the art, will undoubtedly soon minimize this source of trouble.

25 Certain phases of electric power transmission which lend themselves to standardization should be so standardized by some authority that there would be some basis of comparison as to their reliability.

SITUATIONS

26 It is possible to define a number of fairly common situations of power supply for industrial plants and to determine certain limits that it is well to keep in mind when making a comparison in which reliability, cost, conservation and policy are all considered.

27 An attempt is made in the following pages to outline a few such situations, and in doing so only demands of power of 500 kw. or more are considered and these entirely in the form of electrical energy.

Situation A. An industrial plant which has no water power and no demand for exhaust steam or hot water.

28 If a reliable central plant having several times the capacity required for the industry in question existed within reach it would ordinarily be policy to purchase power even at some increase in cost over what the power could be produced for in an isolated plant. It may be assumed that the money which must otherwise be invested

in a power plant would bring additional profit to the industry if invested in manufacturing machinery, buildings or supplies. The management of the industry could be more specialized and conservation of fuel should also be a result.

29 Figs. 1 to 12 (see pages 553 to 565) give the approximate cost of steam power from isolated plants under various conditions and form a basis to determine the rate which it would be policy to pay for purchased power, taking all things into consideration. The load factor in the diagrams is based on the number of hours the plant is in operation.

Situation B. An industrial plant which has a water power of ample capacity to carry the entire load a portion of the time, but must have auxiliary power in some form during low-water periods and has no use for exhaust steam or hot water:

30 The cost of the auxiliary power other than cost of fuel and plant depends largely upon the following:

a Extreme minimum stream flow, which determines the size of auxiliary plant required

b Variation of stream flow throughout the year, which determines the number of times the auxiliary plant must be started

c Pondage available, which determines the uniformity of demand on the auxiliary plant when in operation and the amount of banking of fires

d Completeness of water-power development, which determines the proportion of the total load to be obtained from the auxiliary plant

e Proximity of water power to auxiliary plant, which determines the cost of attendance.

31 If the average output of a water-power installation is 1000 kw. and an auxiliary steam plant of 500 kw. capacity is necessary to furnish supplementary power and must develop 25 per cent of the total power required, the load factor on the auxiliary plant will be about 50 per cent and the cost per kw-hr. of supplementary power would probably be somewhat larger than power obtained from a straight steam plant of the same size and for the same variation in load.

32 This is under the assumption that no saving in attendance will result. Some saving in attendance would result under favorable conditions and would probably make up for the greater variableness

of load on an auxiliary steam plant than would be the case with the average straight steam plant. Most problems coming under this situation can be worked out in a similar manner. In most cases where auxiliary power can be obtained from a central plant of some size and without extensive transmission lines, it should be possible to purchase it at less cost than it can be produced from an auxiliary plant, as the diversity factor on the large plant would ordinarily take care of a reasonably variable demand without much additional cost.

Situation C. An industrial plant which has a small water power, of insufficient capacity to carry the entire load at any time, and has no use for either exhaust steam or hot water.

33 Many industries were started at a time when steam power was inefficient and costly and when the demand for large and constant sources of power was not so important as at present. This naturally led them to locate where water power could be developed at small cost and which would serve all their purposes for the time being. Most of these industries which proved successful soon required larger and more constant sources of power than could be obtained from their local water power, and in many cases the water power soon became a very small portion of the total power required. Very few of these small water powers were abandoned where the industry itself prospered, although in many cases they would be found to operate at a loss if all proper charges were made against them. With others the use of water for condensing and manufacturing purposes required the maintenance of dams, ponds and other structures, which made it possible to consider a large portion or all of the fixed charges against such structures as were properly chargeable to other parts of the industry than water power, thus again making the water power a profitable source of power.

34 Electrical transmission of power has made it possible to utilize many of these small water powers more fully, as their use is not any more limited to the machinery to which they are mechanically connected, but can be used wherever power is required. In some industries where there often is necessity for overtime, night and Sunday work in some departments a small water power is valuable to carry such loads when it would otherwise have to be carried by a steam plant at inefficient part load and at considerable cost in attendance. Most small water powers require no more attendance than is necessary to start and stop the turbines. Still more recently

the question of fuel conservation and the shortage of fuel for steam power has enhanced the value of small water powers, both from the economic standpoint of saving fuel and as an insurance to an industry possessing one that it will have at least a portion of the power required, independent of the coal supply.

35 Such water powers may be the means of completing stock in process at a vital time, or of filling valuable orders, or keeping together at least a small part of an organization when other sources of power fail.

36 Unfortunately, measured in the light of improvement in the art of hydroelectric development in recent years, most of the existing small water powers and many larger ones are extremely inefficient. One of the greatest sources of fuel conservation exists in the redevelopment of water powers electrically and efficiently. Twenty to thirty per cent more power can frequently be obtained from the same amount of water and to this must often be added the saving due to electrical transmission and the saving in wasted water on account of the more flexible use of the power. Even where large ponds are available the demand for power and the supply of water cannot always be synchronized where the use of the power is limited to directly connected machinery, to the same extent that it can when the power is generated electrically and used at will.

37 It is evident from the foregoing that the value of these small water powers can no longer be determined from a purely investment standpoint, in which the cost of a certain number of kilowatt-hours produced by water or by water and steam is compared with the cost of obtaining the same number of kilowatt-hours from a straight steam plant or from purchased power. The problem is more complex and must include power reliability and fuel conservation.

38 The cost of the power required by an industry other than that obtained from its own water power in a situation of this kind is largely governed by the same limitations that have been mentioned under the previous situation. If such additional power is obtained from a steam plant supplementary to the water power or to which the water power may be supplementary, the size of the steam plant depends upon the extreme minimum water power available. The load factor on the steam plant depends upon the amount of water power available and to some extent upon the use made of it. Pondage, if wisely used, will decrease the size of the steam plant required and increase the load factor under which it operates.

39 If the capacity of the steam plant required to carry a load

independent of water power is 1000 kw. and it would operate at 75 per cent load factor under these conditions, this load factor would be reduced to 50 per cent if the steam plant were to be operated with a supplementary water power developing an average output of 250 kw.

40 If the capacity of a steam plant is 1000 kw. and it would operate with a load factor of 50 per cent on a 24-hr. basis without water power, having an average load of 250 kw. for 15 hr., the load factor on it on a 9-hr. basis would be increased to about 85 per cent if the water power developed an average of 250 kw. and carried all the 15-hr. load.

41 Many cases can be similarly worked out and in all of them the cost of the steam power can be approximately determined by reference to Figs. 1 to 12 after the load factor is determined.

42 Purchased power is an advantage in many cases, particularly where the ponds are small and considerably more water power can be developed if the operation of the supplementary steam plant need not be taken into consideration.

43 There is a large field for fuel conservation in connection with water powers attached to industries which operate for only 2700 to 3000 hr. annually. Either reciprocal relations should be worked out between such plants and central plants or the central plants should lease the water powers and furnish the lessor with the power required at a proper cost. The lessor could furnish the attendance at very small cost in most cases.

Situation D. An industrial plant which requires all or more than all of the heat which can be made available from a steam-power plant in the form of either low-pressure steam or hot water or both.

44 Many industries such as paper and textile mills require large quantities of low-pressure steam and hot water in their manufacturing processes, and in the colder parts of the country some low-pressure steam is also required for heating.

45 In many industries of this kind the total demand for low-pressure steam for manufacturing and heating purposes is in excess of the steam required to produce power, but there is difficulty in using any large quantity of low-pressure steam, such as could be made available if a steam prime mover of the non-condensing type were used, because of a lack of synchronism between supply and demand. Occasionally, however, an industry is found where conditions are such, or the process of manufacture can be arranged to be such, that

the practicable supply of low-pressure steam can all be used. The demand need not necessarily be the same as the supply as long as it is always larger, as the additional supply can easily be obtained from the boilers by means of an automatic differential reducing valve connected in between the high- and low-pressure steam mains.

46 As nearly all industries require some high-pressure steam for certain processes, all steam is generally made at high pressure and the pressure reduced by means of reducing valves. The only difference between the heat available from the low-pressure steam which has passed through a prime mover in producing power and that which has passed through the reducing valve is the difference, if any, in heat lost by condensation and radiation in the two means of pressure reduction and steam distribution. It is evident from the above that the steam-power cost in such a case may be comparable to the cost of water power obtained from a plant where there are no water charges, provided the first cost of the plant is about the same. It should be noted that the cost of the steam-producing part of the steam-power plant in such a case is not chargeable to power, as it would be required in any case.

47 In a straight condensing steam plant of 500 kw. capacity, costing $125 per kw. and operating with a 75 per cent load factor on the basis of 2700 hr. yearly running time, the approximate total cost of power per kw-hr. is 2.10 cents with coal at $8 per ton. About one-half of this, or 1.05 cents per kw-hr., is for coal.

48 If the same size of plant were operating non-condensing and if the cost of the boiler plant and boiler-plant attendance were not considered, the cost of power per kw-hr. would be only about 0.56 cent, which is approximately one-half the fixed charges on the total steam plant and one-third the total attendance and a small charge for coal to compensate for loss by radiation. This is admittedly an extreme case, but it shows the limit which is approachable in many instances.

Situation E. An industrial plant which can use only a portion of the heat which could be made available if all power required were made by a steam-power plant.

49 This is a common situation. Very often the total heat required for manufacturing purposes is in excess of that which could be made available from the prime movers, but either the demand or supply, or both, are variable and the situation cannot be developed to maximum efficiency. In other cases only a portion of the heat

available is required, which may vary all the way from the plant which has use for exhaust steam only for a few months a year for building-heating purposes, which may be as low as 25 per cent of the total, to the plant which would properly come under the preceding situation.

50 Many combinations of prime mover and accessories are possible to best develop a given set of conditions, among which are the following:

a Simple non-condensing engine or turbine, where the exhaust is used either entirely as low-pressure steam or partially for heating water

b Compound condensing engine, where low-pressure steam is obtained from a receiver between the high- and low-pressure cylinders and where required hot water may be obtained from the condenser for purposes for which it may be suitable

c Condensing steam turbine of the extraction or bleeder type, where a portion of the steam is extracted near the low-pressure end of the turbine. This low-pressure steam may be partially used to heat water, or hot water may be obtained directly from the condenser. Where conditions warrant it, the condenser may be operated so that it will be really a heater rather than a condenser a great part of the time, heating water to suit the demand by varying the amount of condensing water at a sacrifice of vacuum on the turbine.

51 Figs. 13 to 20 (see pages 566 to 573) give the approximate cost of steam power from plants of 500 kw. and 1000 kw. capacity operated under various conditions as to load factor and using 25, 50, 75 and 100 per cent of the low-pressure steam available from the prime movers. If hot condensing water is used in addition to the low-pressure steam, where only from 25 to 75 per cent of the low-pressure steam is used, the power costs shown in the diagrams will be reduced somewhat.

52 When making comparisons between cost of power as given in Figs. 13 to 20 and those given in the diagrams in Figs. 1 to 12 for straight condensing steam plants, proper allowance should be made for the cost of that portion of the boiler plant which is not chargeable to making power.

53 For instance, a 500-kw. straight steam plant costing $125 per kw. would be approximately comparable with one costing $75

per kw. if 100 per cent of the low-pressure steam, which could be made available, were used for manufacturing purposes, or with one costing $100 per kw. if 50 per cent of the available low-pressure steam were used.

54 There would be an opportunity for coal conservation as well as for financial gain in many situations of this kind, if the central plants would take over the isolated plants of such industries and tie them in with their distribution systems, operating them to the best advantage of all concerned. Efforts directed toward such arrangements would seem to lead to better results than those which are aimed at shutting down isolated plants entirely. A common complaint coming from many industries is that they are burning nearly or quite as much coal since shutting down their steam-power plants and purchasing power as they did when running with steam.

55 In large industrial plants which cover much ground, the expense connected with the installation of low-pressure steam piping of sufficient size to carry the required amount of steam without excessive pressure drop and the loss of heat by radiation and condensation will sometimes be such that the use of low-pressure steam will not be warranted if it is to be supplied from a single steam plant. In such a case it is generally cheaper to use high-pressure steam for at least the more remote parts of the industry, and sometimes for all, and obtain the power required from a plant operating as a straight condensing plant or by purchase from a central plant. The use of a number of steam plants distributed to suit the low-pressure steam requirements would generally not be warranted on account of the excessive cost of attendance, duplication of fixed losses, greater cost of power installation due to smaller units, numerous buildings, difficulty in getting condensing water and delivering coal, etc.

Situation F. An industrial plant which has a water power of ample capacity to carry the entire load a portion of the time, but must have auxiliary power in some form during low-water periods and could use all heat which would be available from a steam-power plant.

56 Considered from the standpoint of cost of power alone, the cost of water-power development would have to be very low in such a case to compete with the steam power which is practically a by-product of the industry.

57 To the cost of the water-power development must be added the cost of the necessary auxiliary plant to carry a portion of the

load during low-water periods, ice troubles, backwater, etc. The cost of the power is then the total of the fixed charges, attendance and supplies for both the water power and auxiliary plant, plus the net cost of the power produced by the auxiliary plant. The size of the auxiliary plant and the extent of its output would depend upon the factors already discussed under Situation B.

58 The only conservation of fuel would result from the difference in saving in the 10 to 20 per cent heat loss by radiation in producing the by-product steam power from the continuously operating steam plant and the auxiliary plant. There would be some additional saving of fuel in case of overtime work if the water power should make it possible to shut down the steam plant when it would otherwise run under uneconomical conditions.

59 The problem under this situation is generally to arrive at the cost of investment which would be warranted to develop a water power.

60 The diagrams can be used to arrive at approximate results as follows:

PROBLEM 1. Determine the permissible water-power development cost to arrive at the same yearly cost of power that would result from a steam plant operating alone, the details being as follows:

(*a*) *Steam Plant*

1 Size of plant, 1000 kw.
2 Load factor, 75 per cent
3 Use of low-pressure steam, 100 per cent
4 Cost of plant chargeable to power, $50 per kw.
5 Cost of coal, $6 per ton
6 Operating time, 2700 hours yearly.

61 From Fig. 20 the cost of power per kw-hr. would be approximately, 0.52 cent. The total yearly cost would be 1000 kw. × 0.75 × 2700 hr. × $0.0052 = $10,530.

(*b*) *Water-Power Plant with Auxiliary*

1 Size of plant, 1000 kw.
2 Size of auxiliary plant, 500 kw.
3 Load factor on auxiliary plant, 50 per cent
4 Use of auxiliary-plant low-pressure steam, 100 per cent
5 Cost of auxiliary plant chargeable to power, $75 per kw.
6 Cost of coal, $6 per ton
7 Operating time of auxiliary plant, 1350 hours yearly
8 No overtime running of water power.

62 From Fig. 16 the cost per kw-hr. of supplementary steam power would be about 0.96 cent. The total yearly cost of supplementary power would be 500 kw. × 0.50 × 1350 hr. × $0.0096 = $3240.

63 To break even, the yearly cost of water power could then be $10,530 − $3240 = $7290.

64 If the cost of attendance, oil, waste and supplies is $2500, there remains $4790 to pay fixed charges on the water-power investment. If fixed charges are 10 per cent the investment could be $47,900, or at the rate of $47.90 per kw. The price of coal makes very little difference in a situation of this kind.

Situation G. An industrial plant which has a water power of ample capacity to carry the entire load a portion of the time, but must have auxiliary power in some form during low-water periods and could use only a portion of the heat which would be available from a steam-power plant.

65 This situation presents practically the same problem as the preceding one. The expenditure on water power which could be made to arrive at the same yearly cost of power as that made with a steam plant alone, would depend upon the extent of use of low-pressure steam and hot water and the auxiliary-plant cost and power required from it.

66 In the case of large industries where the distribution of low-pressure steam is expensive, the auxiliary plant can sometimes be located near the point of greatest use of low-pressure steam and the balance of manufacturing and heating steam distributed at high pressure. Hot water can more easily be distributed over large areas than low-pressure steam. Very often the question of condensing-water supply and coal delivery will dictate the location of the auxiliary plant, with the result that all manufacturing and heating steam is distributed at high pressure.

67 The diagrams can be used to arrive at approximate results as follows:

PROBLEM 2. Determine the permissible water-power development cost to arrive at the same yearly cost of power that would result from a steam plant operating alone, the details being as follows:

(*a*) *Steam Plant*

1 Size of plant, 1000 kw.
2 Load factor, 75 per cent
3 Use of low-pressure steam, 25 per cent
4 Cost of plant chargeable to power, $125 per kw.

5 Cost of coal, $8 per ton
6 Operating time, 2700 hours yearly.

68 From Fig. 17 the cost per kw-hr. would be approximately 1.96 cents. The total yearly cost would be 1000 kw. × 0.75 × 2700 hr. × $0.0196 = $39,690.

(*b*) *Water-Power Plant with Auxiliary*

1 Size of plant, 1000 kw.
2 Size of auxiliary plant, 500 kw.
3 Load factor on auxiliary plant, 50 per cent
4 Use of auxiliary-plant low-pressure steam, 50 per cent
5 Cost of auxiliary plant chargeable to power, $100 per kw.
6 Cost of coal, $8 per ton
7 Operating time of auxiliary plant, 1350 hours yearly
8 No overtime running of water power.

69 From Fig. 14 the cost per kw-hr. of supplementary steam power would be about 2.14 cents. The total yearly cost of supplementary power would be 500 kw. × 0.50 × 1350 hr. × $0.0214 = $7222.50.

70 To break even, the yearly cost of the water power could then be $39,690 − $7222.50 = $32,467.50.

71 If attendance, oil, waste and supplies cost $2467.50, there remains $30,000 which can be applied to the water-power development as fixed charges.

72 With 10 per cent fixed charges an investment of $300,000 would be warranted. This would be at the rate of $300 per kw.

73 With coal at $5 per ton and other conditions remaining the same, an investment of only about $225 per kw. would be warranted.

Situation H. An industrial plant which has a small water power, of insufficient capacity to carry the entire load at any time, and which would have use for all heat made available by a steam-power plant at all times.

74 Most small water powers operating under the above conditions would show a loss if all proper charges were made against them. The probability of making a water power of this kind pay for itself lies in its possible operation for overtime work and in carrying a part of the load in case of breakdown of the steam plant or in case of shortage of fuel.

75 A pond of some size and electrical development increase the possibilities of advantageous use of such small water powers under the above situation.

76 Conservation of fuel would result from the use of the water power for overtime work, if the steam plant could be completely shut down during such times.

CONCLUSIONS

77 Reliability of power supply is of much greater importance to the average industry than the cost of power. If the cost of power were doubled, it would be hardly noticed on the balance sheet of many industries, but shutdowns and speed drop or variation of speed may make a decided difference.

78 Cost and reliability being nearly equal, it would ordinarily be policy to purchase power where available. If the central plant from which the power is purchased is relatively large and has a fair load factor, this would tend toward fuel conservation.

79 Where an industry requires considerable heat for manufacturing and heating purposes, power can generally be made cheaper than it can be purchased, and fuel would also be conserved by making rather than purchasing power in such a case.

80 Water power owned by an industry in many cases bears the same relation to it as does purchased power. If it is located at the industry it is often a form of reliability insurance to maintain a water power, even if there is no apparent saving due to its use. Water powers that save coal should be maintained in any case, and there is a splendid opportunity to save fuel by redevelopment of inefficient water powers.

81 There exists a field for fuel conservation and financial gain for both central plant and industry, in the possibility of isolated-plant operation by the former. In the case of water powers owned by industries running only eight and nine hours a day, the saving is of decided importance. Under certain conditions the saving which would result from central-plant operation of isolated steam plants is also considerable.

DIAGRAMS GIVING APPROXIMATE COST OF STEAM POWER FOR PLANTS OF DIFFERENT CAPACITIES OPERATING UNDER CERTAIN STATED CONDITIONS

For References to the Illustrations, see Pars. 29 and 51 of the Paper

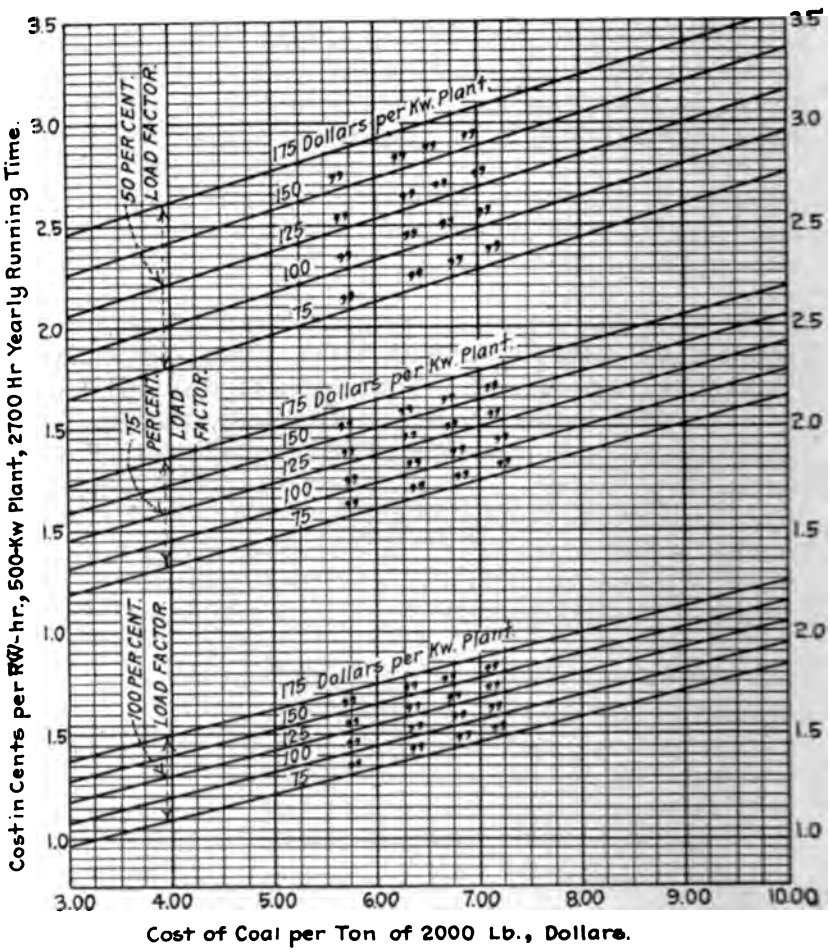

FIG. 1 APPROXIMATE COST OF STEAM POWER FROM 500-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

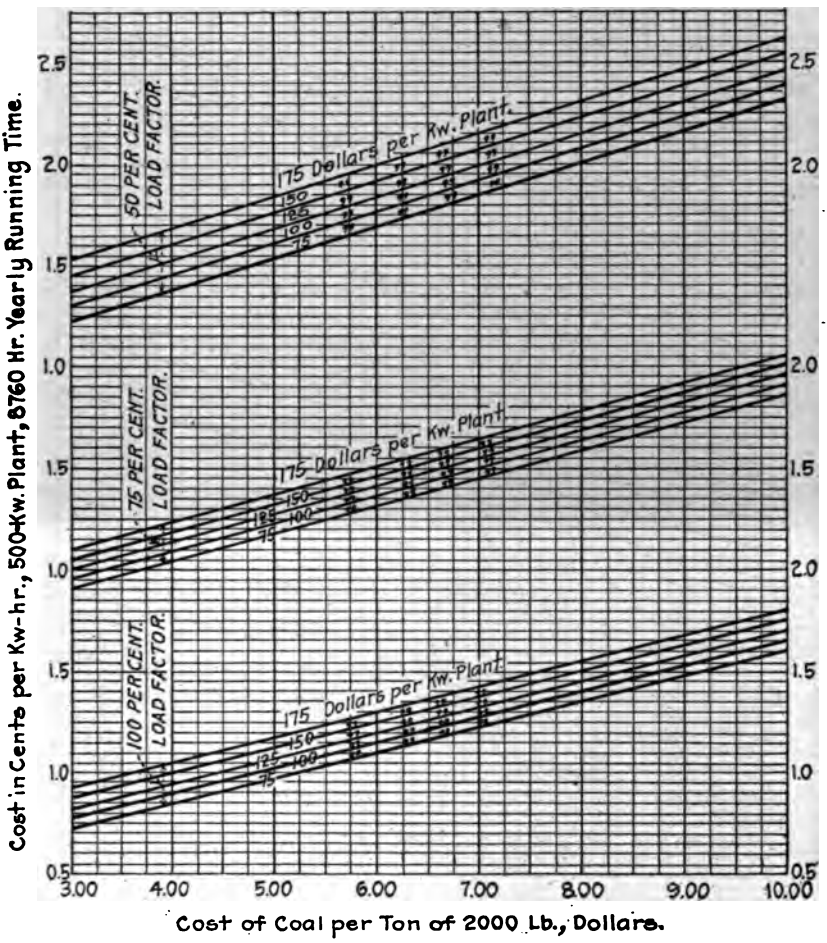

FIG. 2 APPROXIMATE COST OF STEAM POWER FROM 500-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

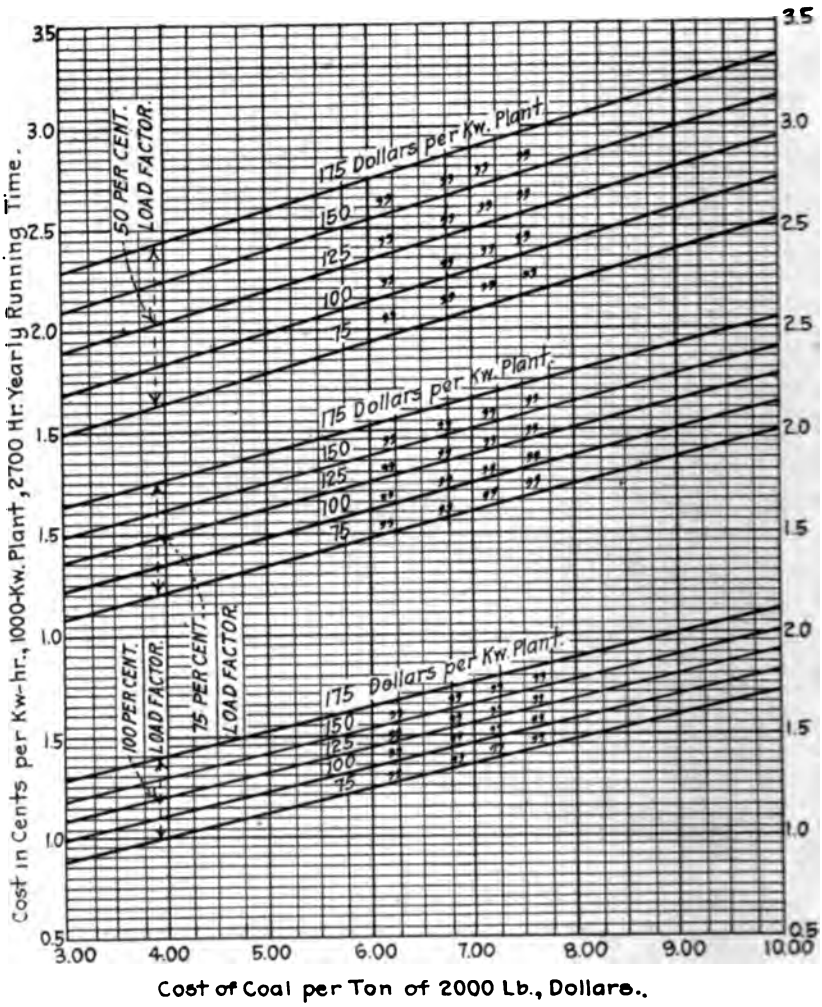

FIG. 3 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

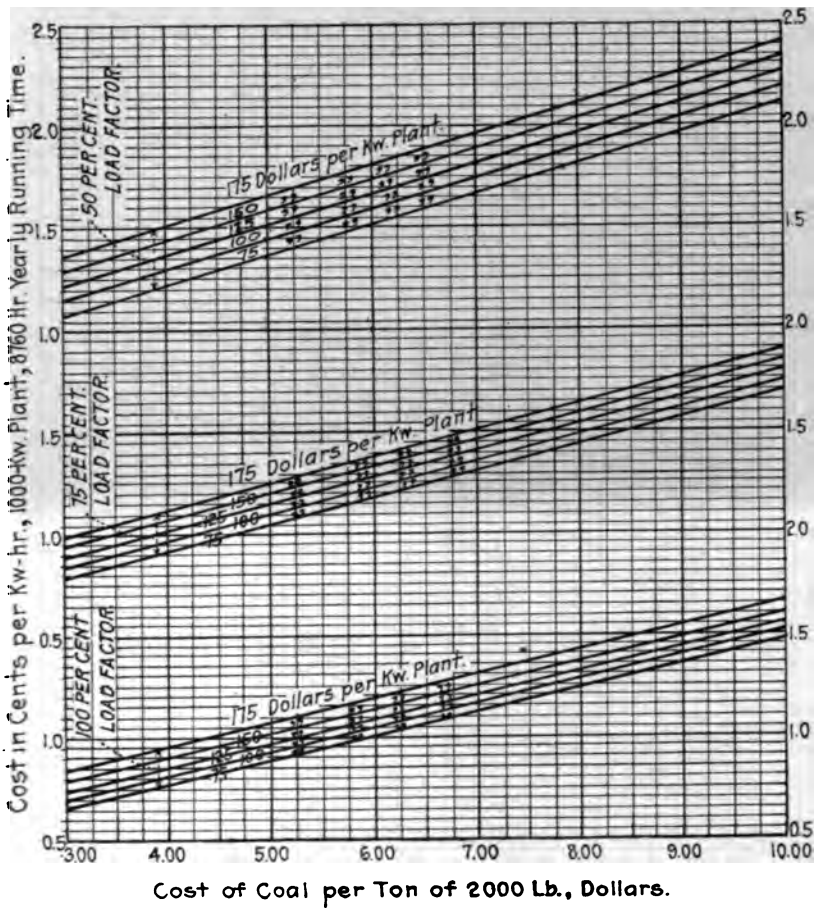

FIG. 4 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

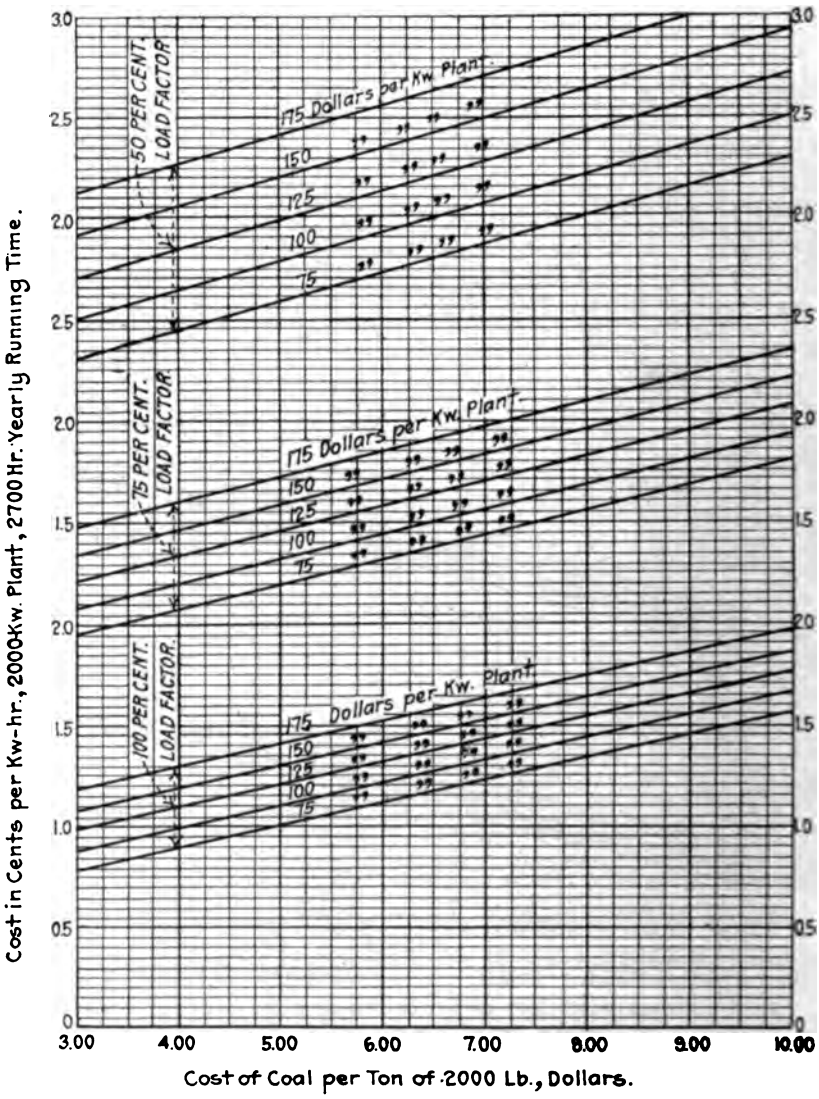

FIG. 5 APPROXIMATE COST OF STEAM POWER FROM 2000-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

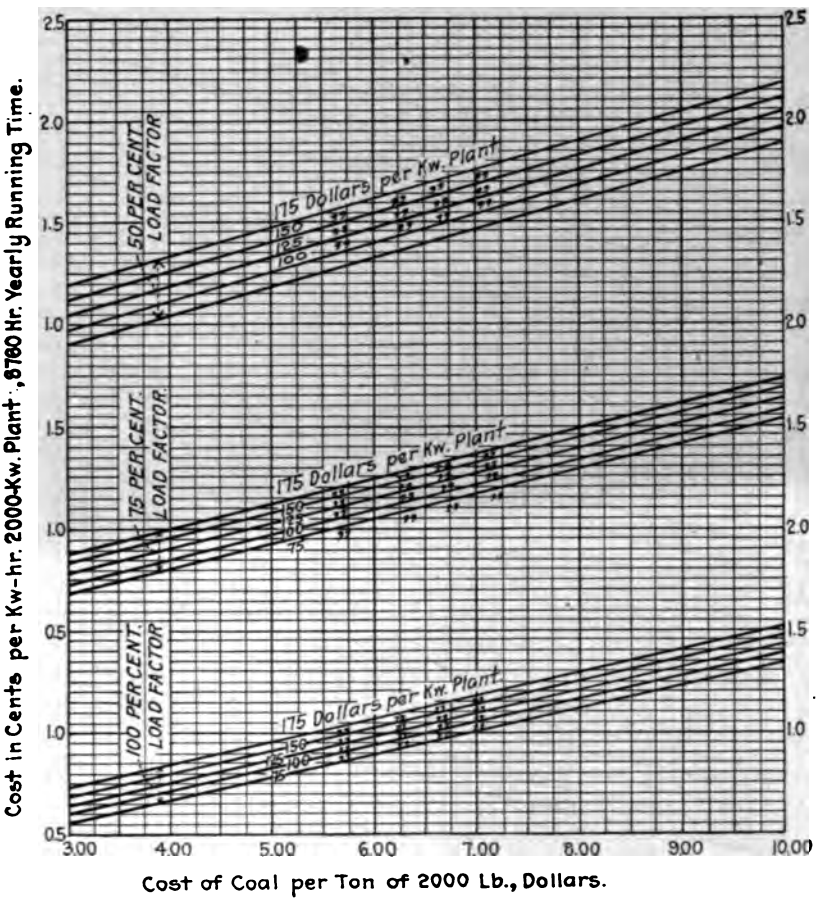

FIG. 6 APPROXIMATE COST OF STEAM POWER FROM 2000-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

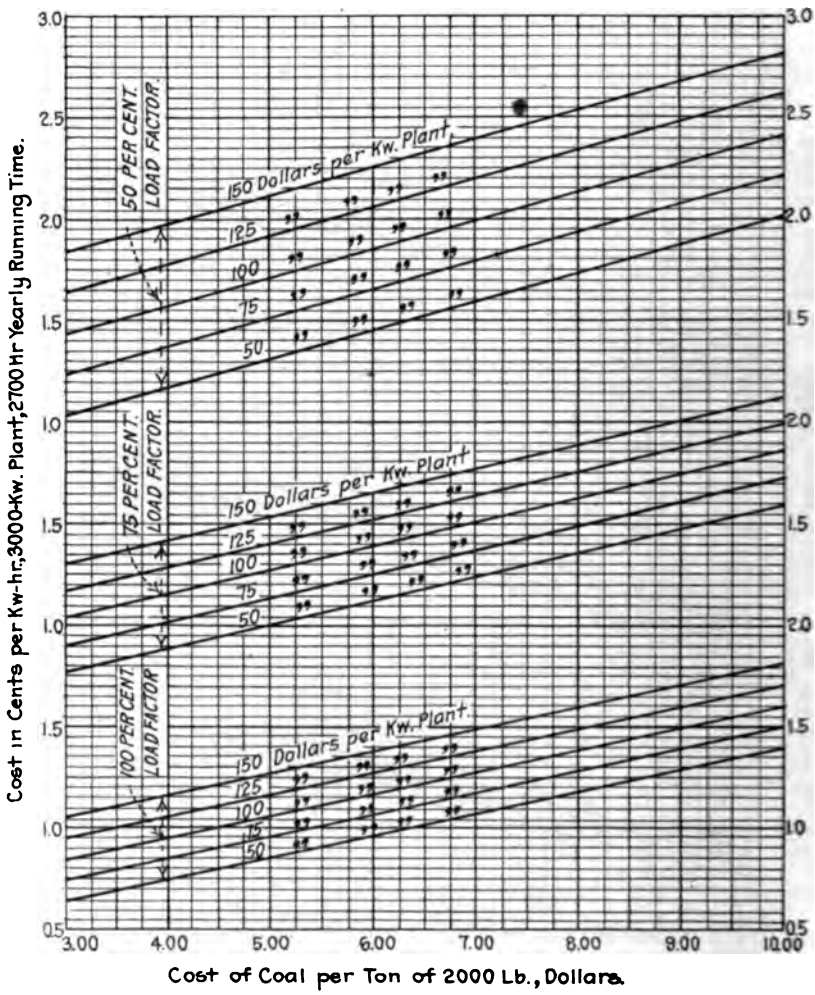

FIG. 7 APPROXIMATE COST OF STEAM POWER FROM 3000-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

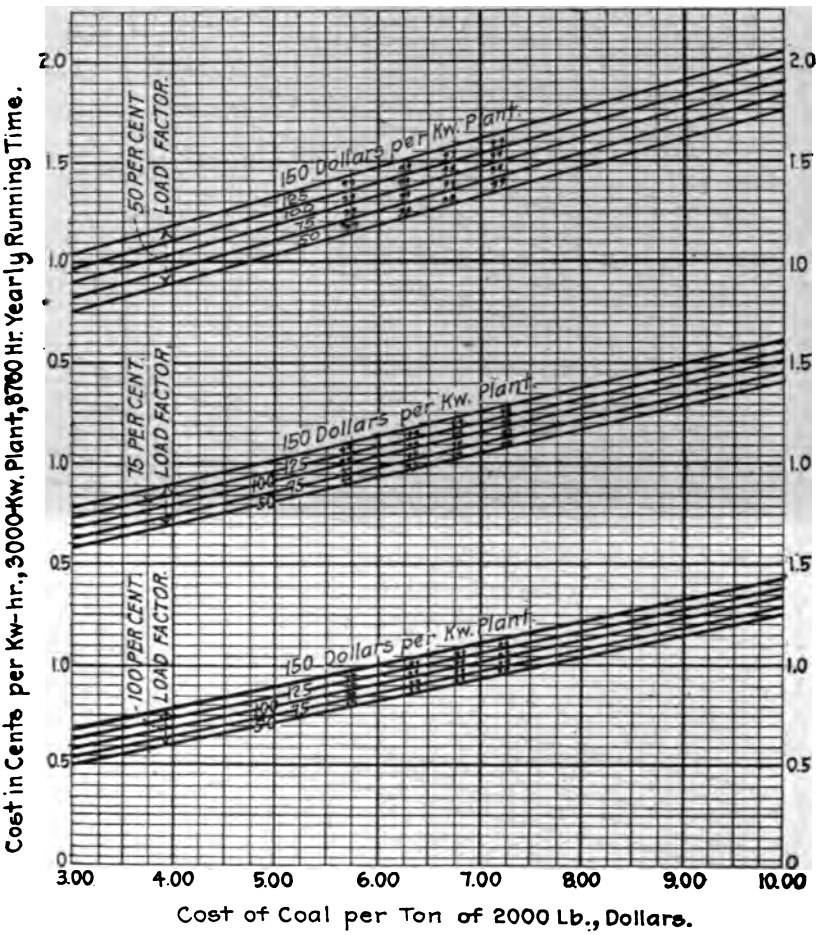

FIG. 8 APPROXIMATE COST OF STEAM POWER FROM 3000-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

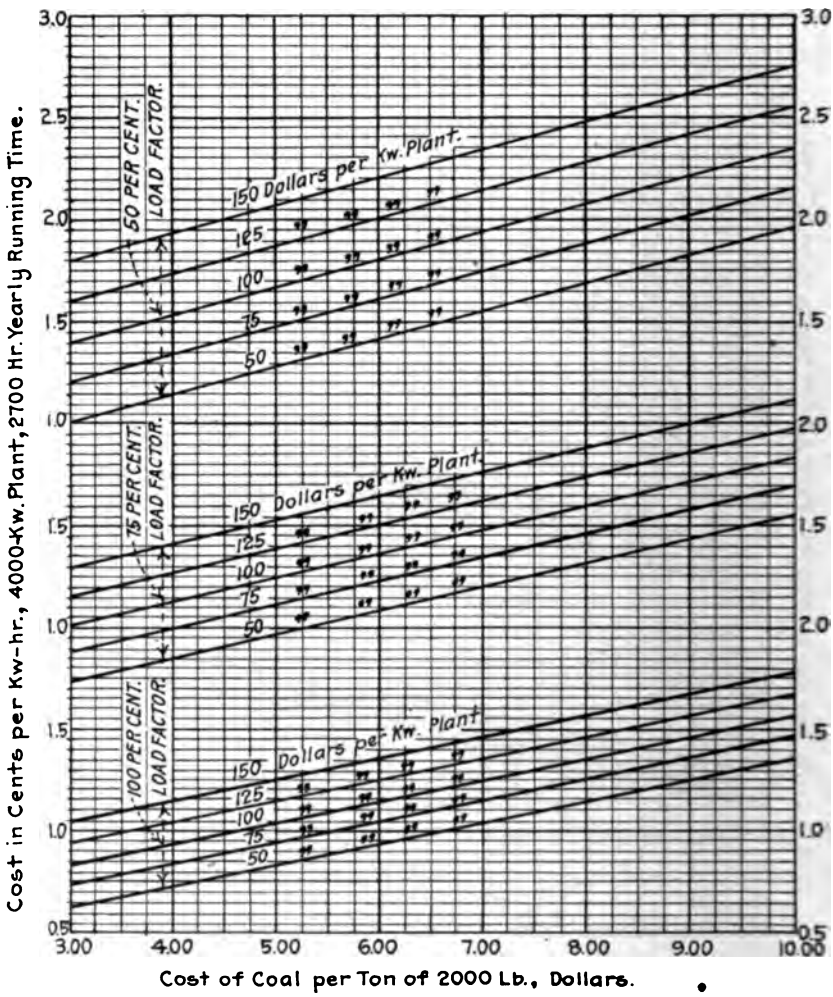

FIG. 9 APPROXIMATE COST OF STEAM POWER FROM 4000-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

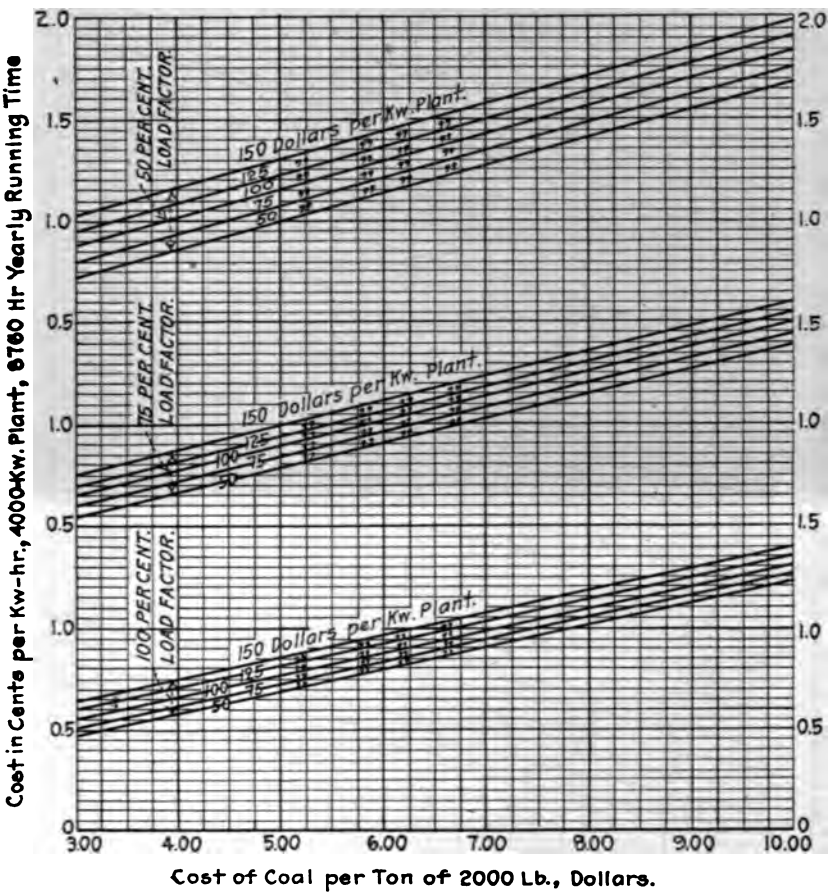

FIG. 10 APPROXIMATE COST OF STEAM POWER FROM 4000-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

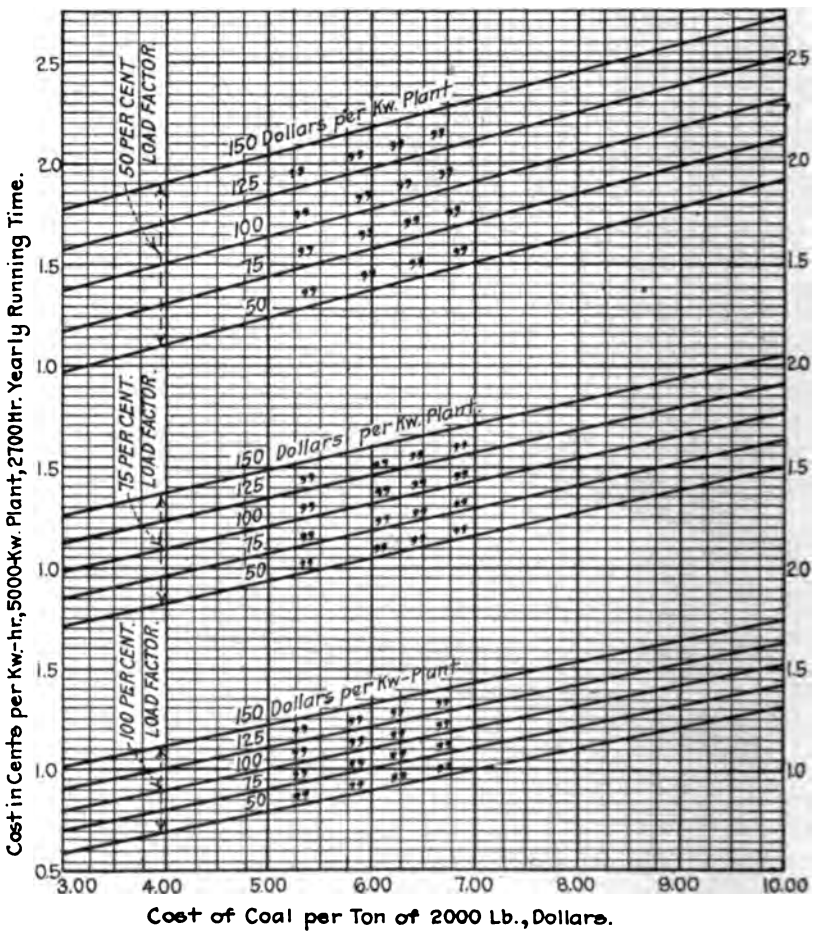

FIG. 11 APPROXIMATE COST OF STEAM POWER FROM 5000-KW. ISOLATED PLANT RUNNING 2700 HR. YEARLY

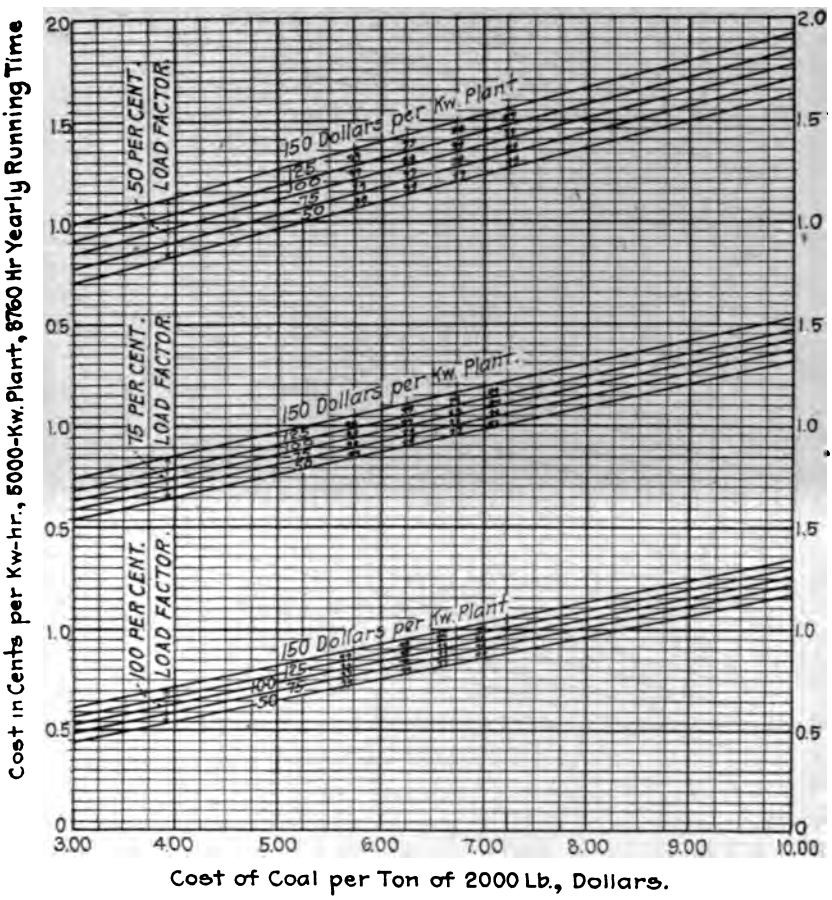

FIG. 12 APPROXIMATE COST OF STEAM POWER FROM 5000-KW. ISOLATED PLANT RUNNING 8760 HR. YEARLY

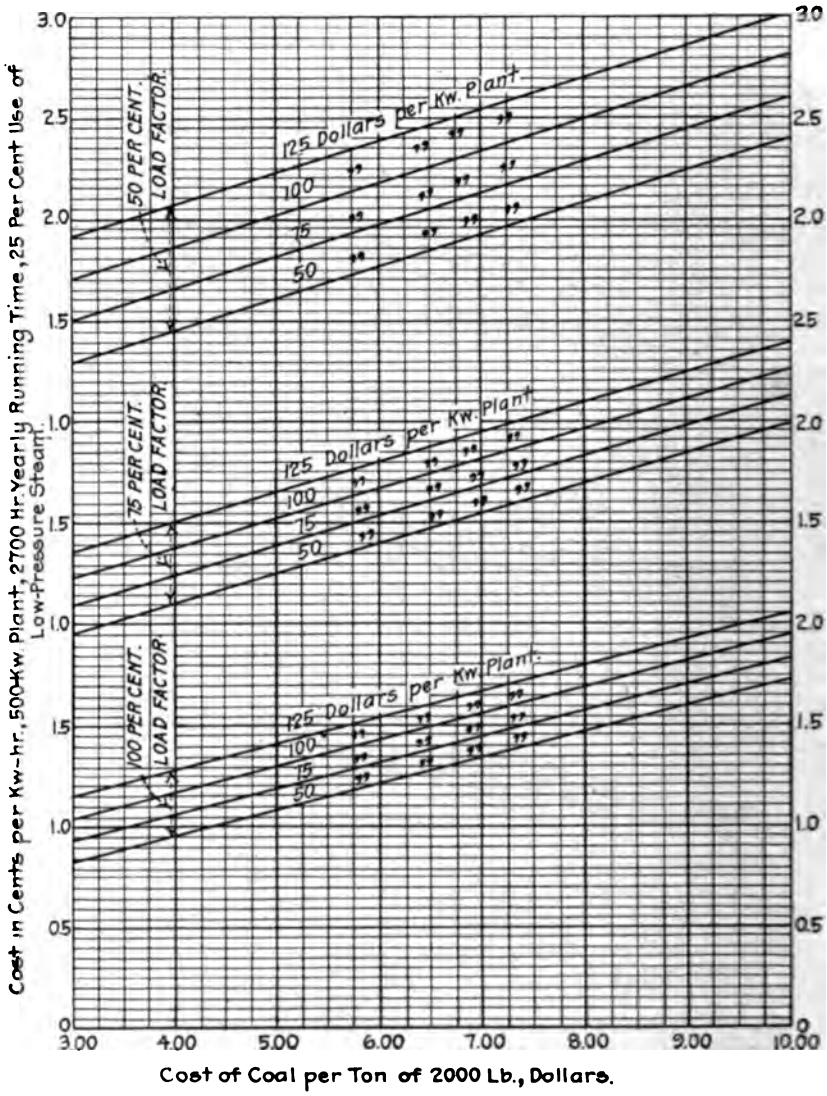

FIG. 13 APPROXIMATE COST OF STEAM POWER FROM 500-K.W. PLANT RUNNING 2700 HR. YEARLY AND USING 25 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

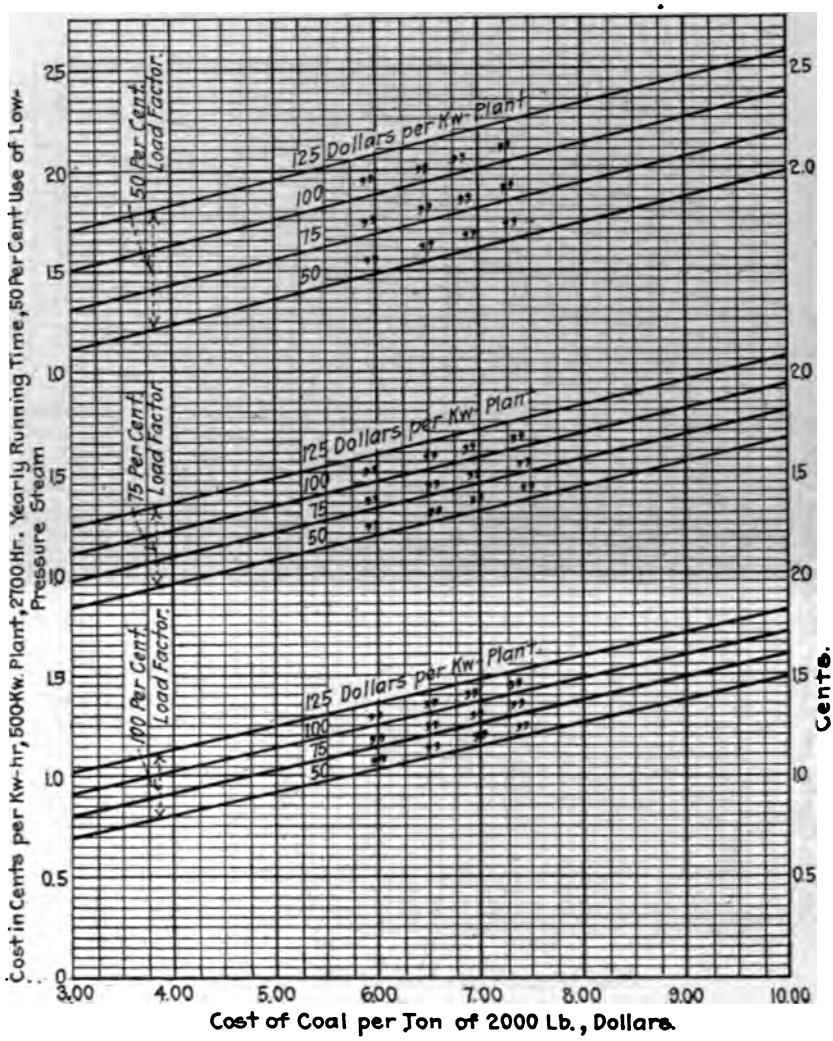

FIG. 14 APPROXIMATE COST OF STEAM POWER FROM 500-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 50 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

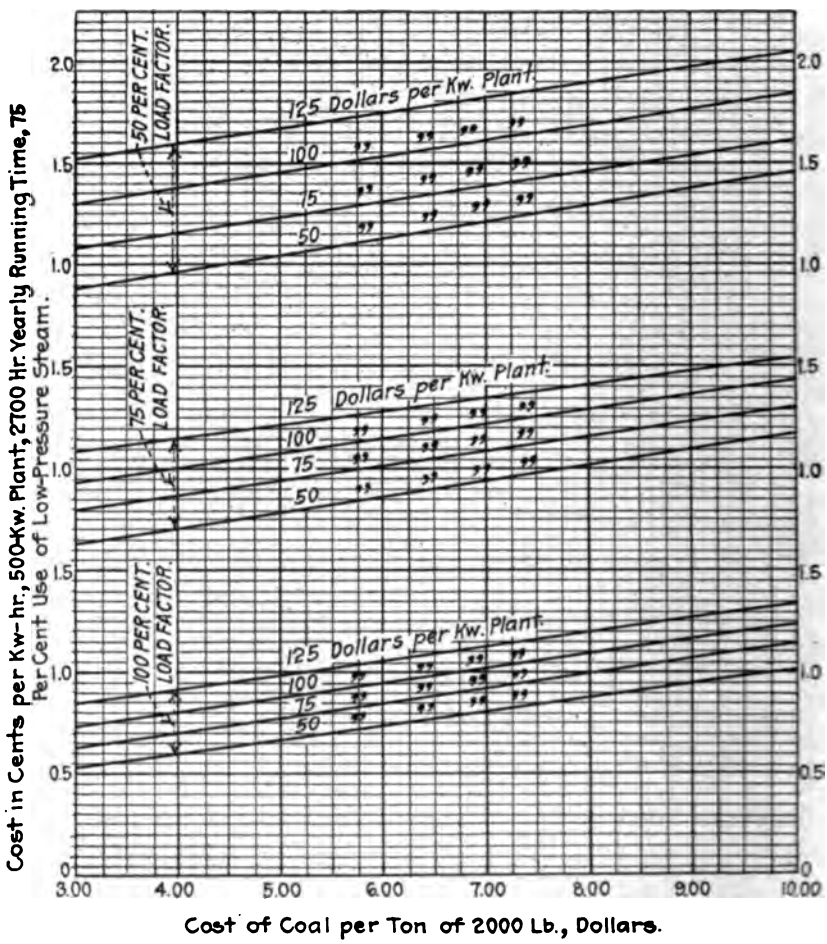

FIG. 15 APPROXIMATE COST OF STEAM POWER FROM 500-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 75 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

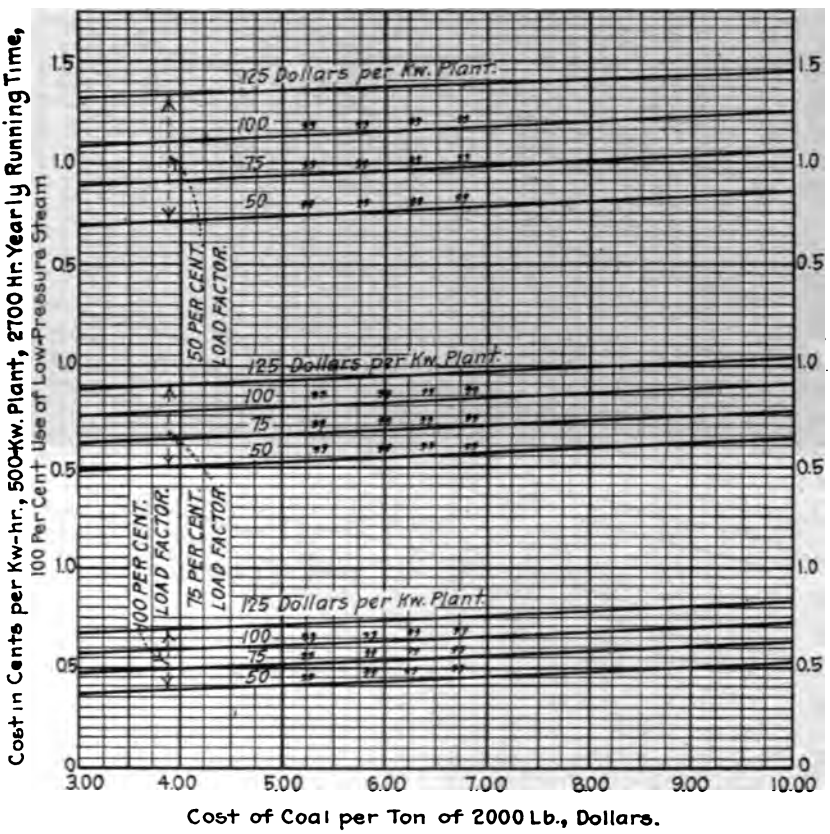

FIG. 16 APPROXIMATE COST OF STEAM POWER FROM 500-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 100 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

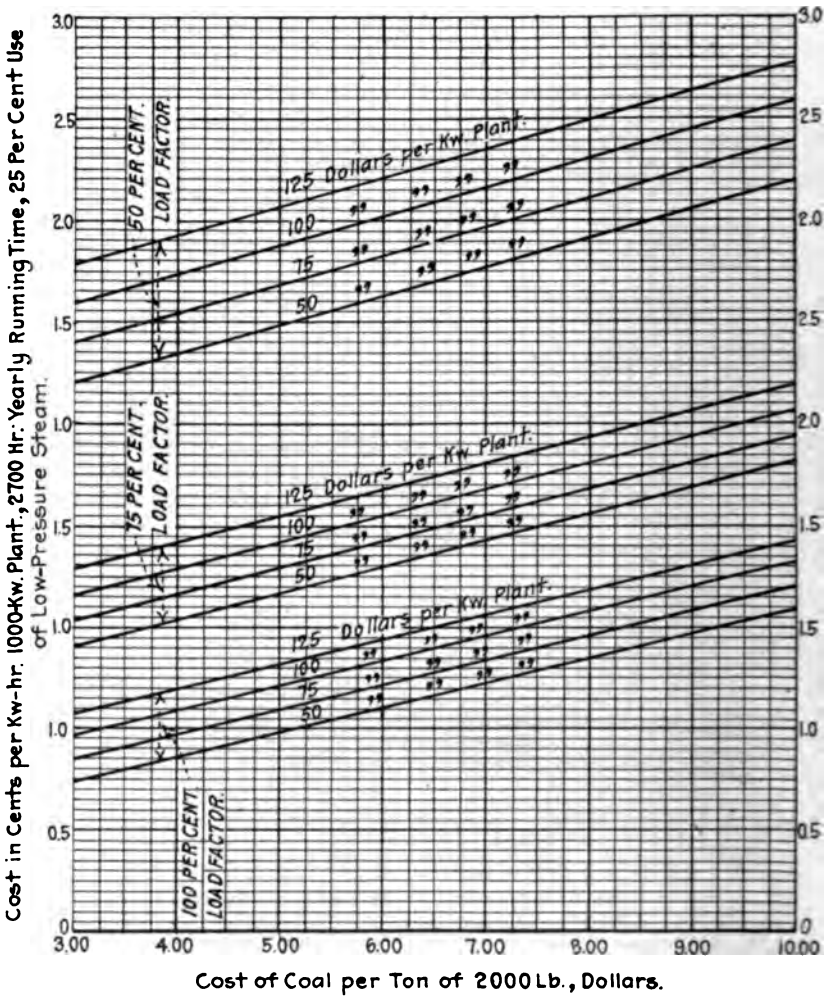

FIG. 17 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 25 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

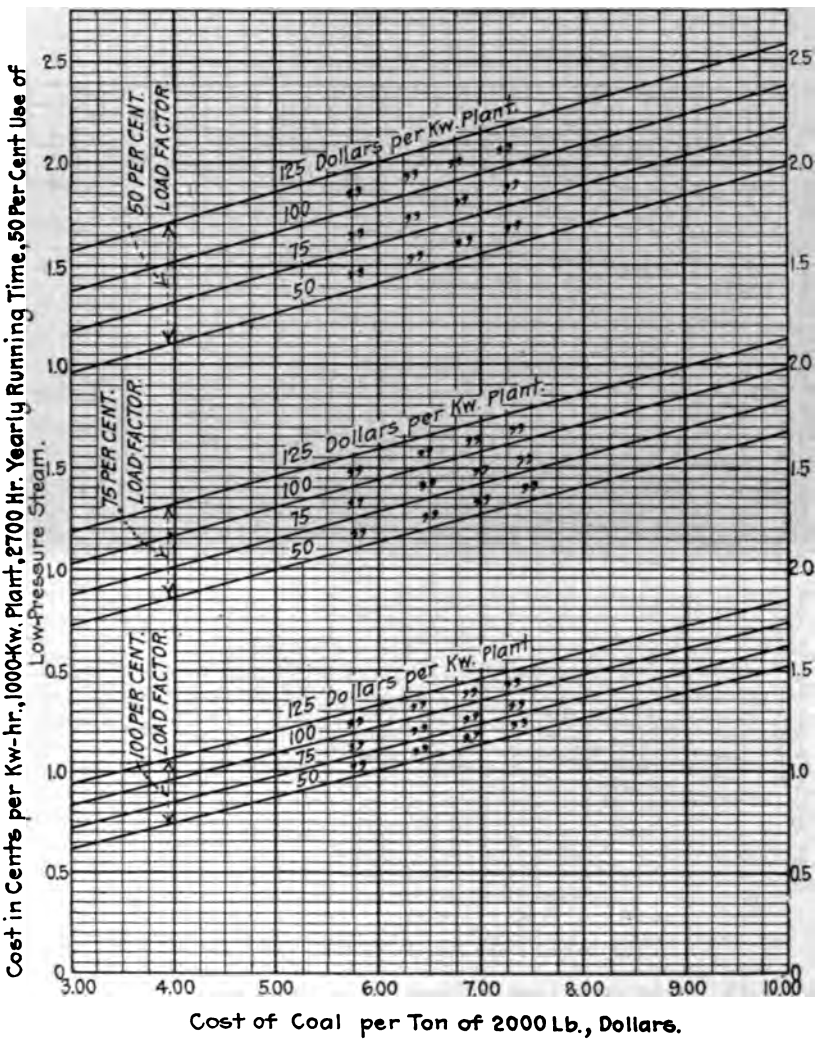

FIG. 18 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 50 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

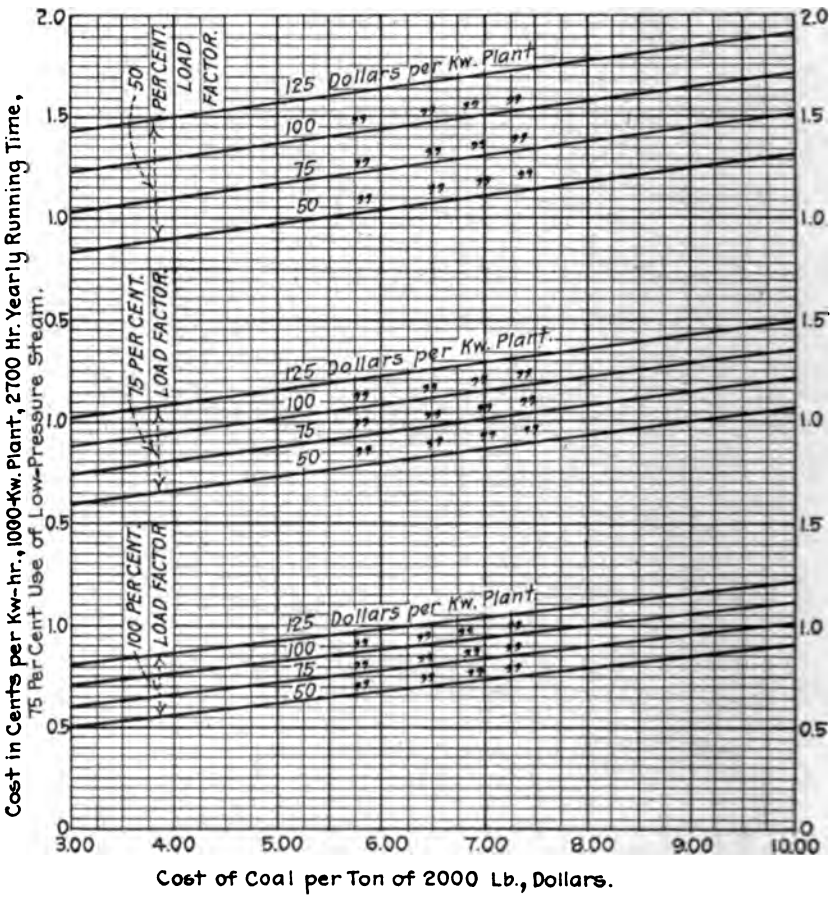

FIG. 19 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 75 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

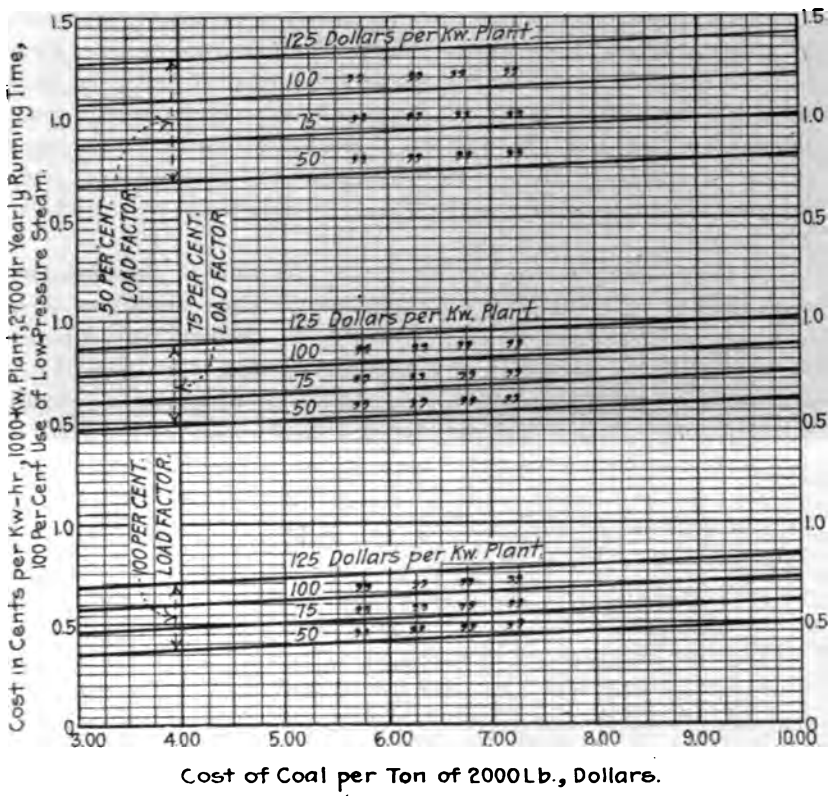

FIG. 20 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 100 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

DISCUSSION

WM. S. ALDRICH (written). A careful examination of Figs. 13 to 20 of the paper showing the cost of power per kilowatt-hour at various load factors and using some proportionate part of the low-pressure (exhaust) steam for heating purposes, reveals four quite distinct applications. These have particular reference to the determination of economic operating conditions for a given plant. That is, for given capacity of plant, cost per kilowatt of installation, running time per annum, and cost of coal per ton. These may be considered the fixed quantities with which one has to deal in comparative studies of operating costs. The load factor and percentage of low-pressure steam for heating may likewise be considered the variables. Thus:

1 *Concentrated vs. Subdivided Power Generation.* Suppose the peak load to be about 5000 kw., and the operating conditions such as to give a load factor of about 75 per cent. Assume cost of plant at $75 per kw., coal at $6 per ton, and a running time of 2700 hr. per annum. Of the number of combinations of generating units possible, which is the most desirable, or most economic in continuous operation, with a load that may range from 50 per cent to 100 per cent of the installed capacity; and with or without steam heat, if district, plant, or other heating may be guaranteed? Quickly to illustrate, take an extreme case:

One 5000-kw. unit, condensing, will generate power under the above conditions at a cost of 1.2 cents per kw-hr.

Ten 500-kw. units, condensing, will bring the cost up to 1.60 cents per kw-hr. But if the exhaust steam is used for heating, we have rapidly decreasing cost of the power production, according to its proportionate use, as follows:

Per cent of low-pressure steam available	25		50		75		100
Cost per kw-hr., cents	1.55		1.32		1.02		0.67
Rate of decreasing cost of power, cents		0.23		0.30		0.35	

Clearly there is some reasonably fixed percentage of utilization of the exhaust steam, under the given conditions, which renders the power cost of the subdivided (500-kw.) units the same as that of the single 5000-kw. unit; that is, at rate of 1.20 cents per kw-hr. Interpolating, this is found at about 60 per cent utilization of the low-pressure steam for heating. Less than this percentage would prove unprofitable; greater, shows increasing economy, even to the point

of reducing the power cost to 56 per cent of its value, for the large single unit. Similarly, a detailed study may be made at 50 per cent and at 100 per cent load factors.

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For convenience of illustration, assume a 1000-kw. plant costing at rate of $75 per kw. installed, with running time of 2700 hr. per annum, and cost of coal at $6 per ton. The following summary from the curves of Mr. Uhl's paper gives at once the data for such sliding scale of operating costs:

Load Factor, Per Cent	Cost of Power per Kw-Hr., Cents				
	Condensing (straight)	At Per Cent Low-Pressure Steam Available:			
		25	50	75	100
50	1.93	1.83	1.61	1.24	0.94
75	1.48	1.42	1.28	0.94	0.65
100	1.24	1.22	1.13	0.68	0.53

With an additional 25 per cent income from steam heating there is even a little less power cost at full load than when running condensing. The even conditions almost prevail at 75 per cent load factor with 50 per cent steam heating, and at 50 per cent load factor with 75 per cent steam heating. The maximum economy is reached at 100 per cent load with all low-pressure steam used for heating; or about 40 per cent of the cost of power under such full-load conditions compared with that running condensing alone.

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4 *Influence of Cost of Coal upon Power Costs with Steam Heat.* In Par. 64 Mr. Uhl states that for the case assumed in the problem the cost of coal makes very little difference. This is markedly shown in Figs. 16 and 20, for the 100 per cent of low-pressure steam available, by the very slight slope of the cost lines for quite a wide range of coal costs — from $3 to $10 per ton. But there is a significant maximum difference of cost, however, within this range for the various percentages of low-pressure steam available. It may be illustrated as follows, assuming a 1000-kw. plant, costing $75 per kw. installed and a running time of 2700 hr. per annum:

Per cent of low-pressure steam available	None	25	50	75	100
Cost per kw-hr. with coal at:					
(a) $10 per ton	1.70	1.70	1.62	1.01	0.61
(b) $3 per ton	0.87	0.84	0.72	0.61	0.46
Cost difference per kw-hr., cents	0.83	0.86	0.90	0.40	0.15

Plotting these values as usual, or otherwise examining their relations by differences, it will be seen that the maximum difference occurs at about 50 per cent use of the available low-pressure steam. Until this point is reached there is only a very slight gain in economy with the coal at $10 per ton; and a little better economy is shown with the coal at $3 per ton. For the lack of a more expressive term we have called this the "uneconomic range" of the heating use of the low-pressure steam.

Beyond the 50 per cent utilization, however, there is very marked increase in economy of the steam heating, with the coal even at $10 per ton, but less increase of economy with the coal at $3 per ton. It would be trite to say, again, as usual, that the higher-priced coal shows greatest gain in economy in the long run for all use of the low-pressure steam above 50 per cent available.

For the 500-kw. plant a similar analysis of Mr. Uhl's curves will show that the most uneconomic point of steam heating is about at 25 per cent use of the low-pressure steam available.

Summing up, we may say that, for the given conditions:

The 1000-kw. plant has a floating range of power costs from operation condensing to about 66⅔ per cent use of exhaust steam.

The 500-kw. plant has a similar floating range to about 33⅓ per cent use of exhaust steam.

Beyond these limits the economy rapidly increases with every additional use of the low-pressure steam; but more rapidly with the high-priced than with the low-priced coal.

ARTHUR T. SAFFORD (written). Many small water powers have been hopelessly outgrown by the demands for more power by textile mills, but in many cases their use of water for mechanical purposes has become of such value that a shortage at any time in the year becomes almost a calamity. This shortage often has to be made up by water purchased from city water works or obtained from driven wells; the former costs approximately 10 cents per 100 cu. ft.; the latter is often hard to find and the quantity doubtful. A large print works, dyehouse and bleachery may easily use from 6 to 12 million gallons daily, which at city rates would cost from $800 to $1600, a sum which would be prohibitive; while the same water under 30 ft. fall would be worth as power perhaps $10 a day. The value of water for mechanical purposes has never been recognized fully by manufacturers in buying and selling mill sites; but has been well known by cities and towns which have taken streams for water-supply purposes.

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He believed it would pay every manufacturer to investigate the reliability of the public-service or local power coming to his plant and see what reserve capacity they might have, what means for transmission were available, and also whether the local company kept up inspection of its plant to produce reliability.

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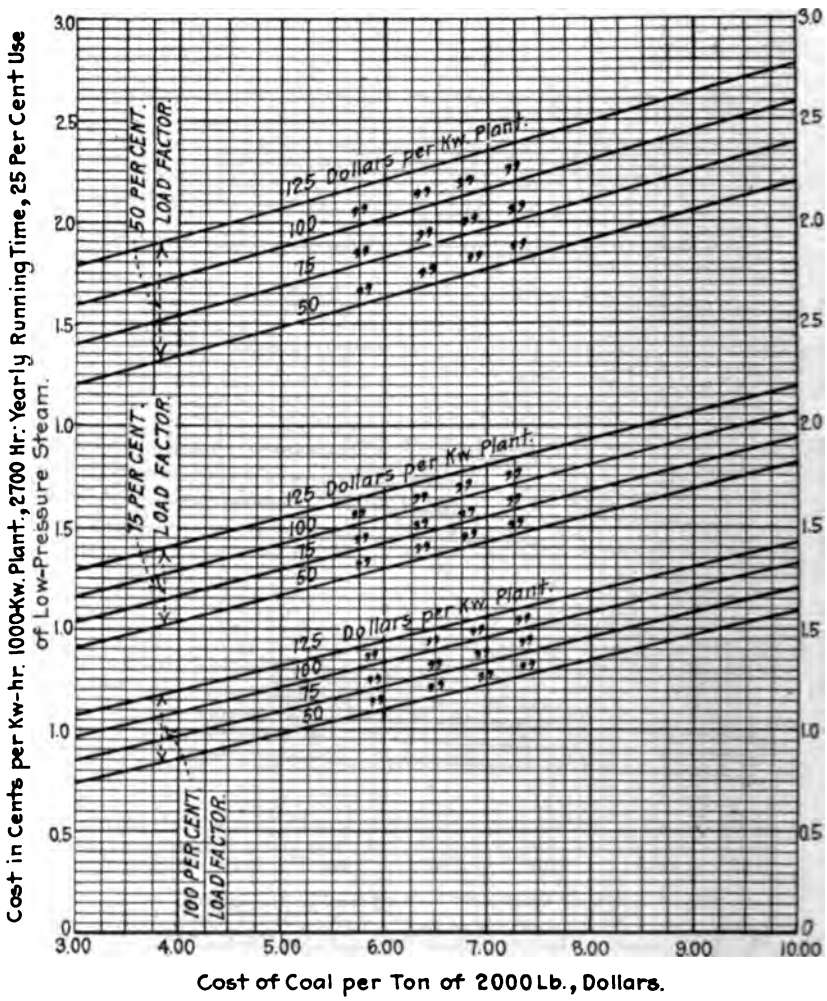

FIG. 17 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 25 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

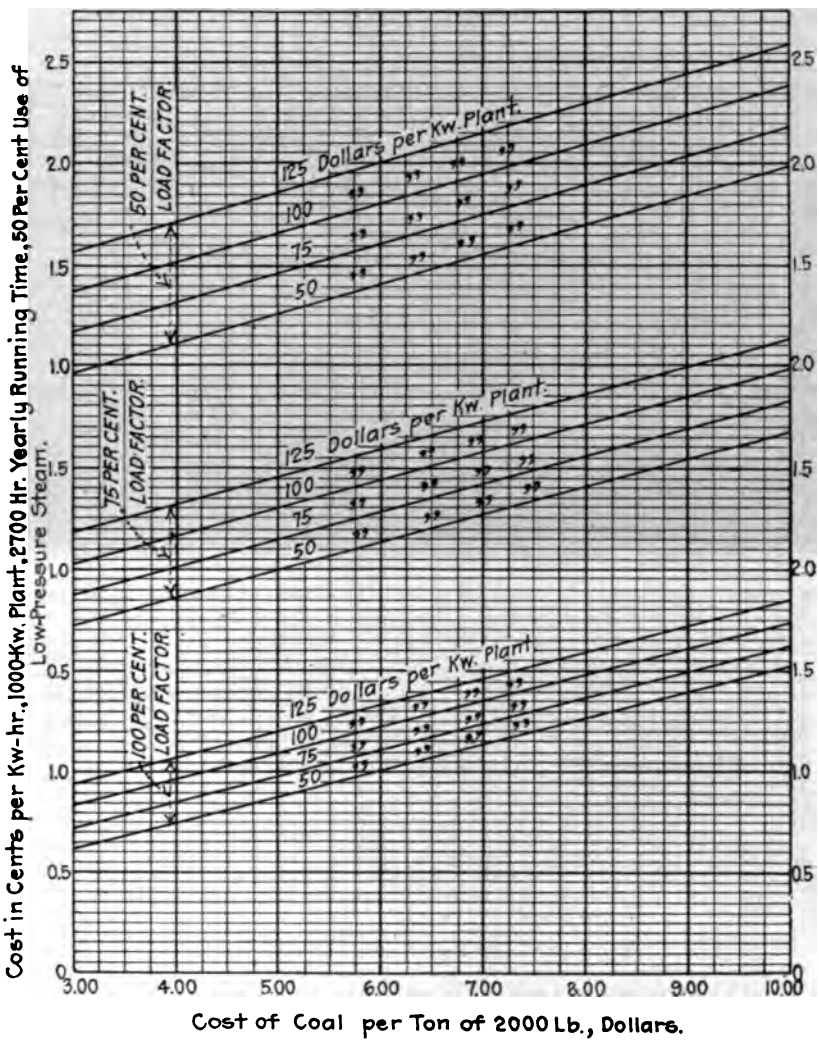

FIG. 18 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 50 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

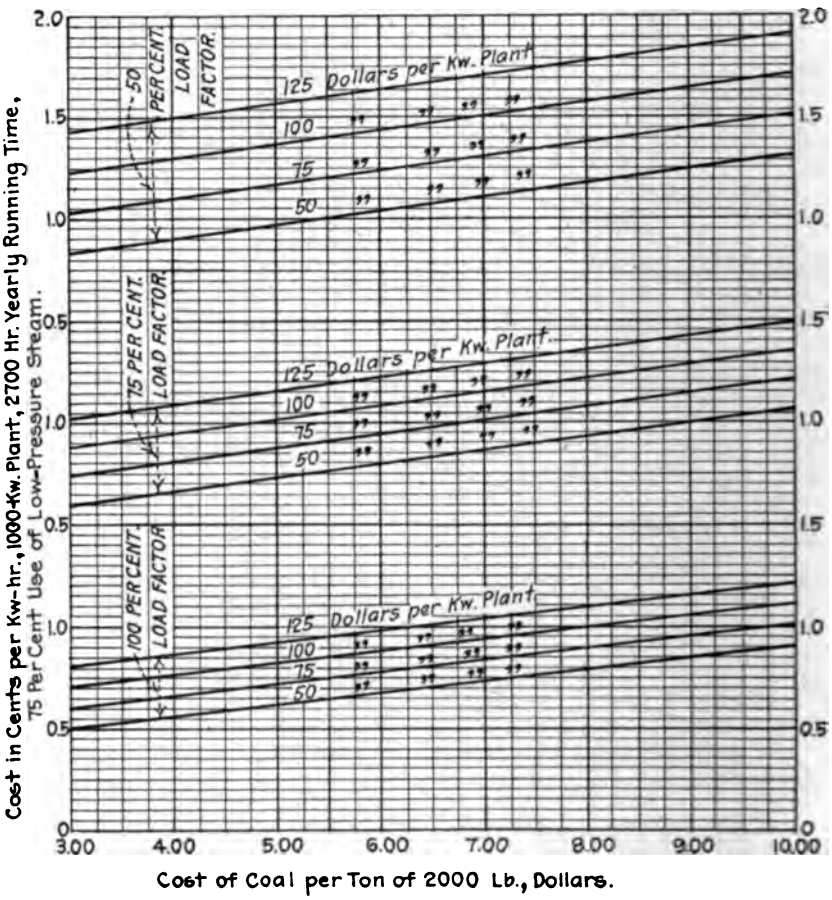

FIG. 19 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 75 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

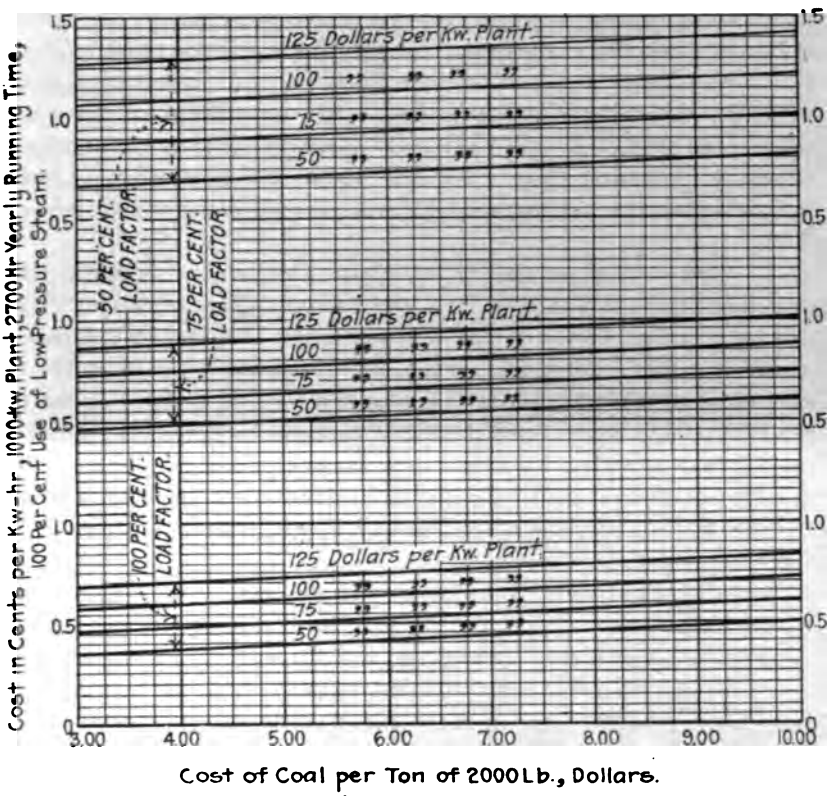

FIG. 20 APPROXIMATE COST OF STEAM POWER FROM 1000-KW. PLANT RUNNING 2700 HR. YEARLY AND USING 100 PER CENT OF THE LOW-PRESSURE STEAM AVAILABLE

DISCUSSION

WM. S. ALDRICH (written). A careful examination of Figs. 13 to 20 of the paper showing the cost of power per kilowatt-hour at various load factors and using some proportionate part of the low-pressure (exhaust) steam for heating purposes, reveals four quite distinct applications. These have particular reference to the determination of economic operating conditions for a given plant. That is, for given capacity of plant, cost per kilowatt of installation, running time per annum, and cost of coal per ton. These may be considered the fixed quantities with which one has to deal in comparative studies of operating costs. The load factor and percentage of low-pressure steam for heating may likewise be considered the variables. Thus:

1 *Concentrated vs. Subdivided Power Generation.* Suppose the peak load to be about 5000 kw., and the operating conditions such as to give a load factor of about 75 per cent. Assume cost of plant at $75 per kw., coal at $6 per ton, and a running time of 2700 hr. per annum. Of the number of combinations of generating units possible, which is the most desirable, or most economic in continuous operation, with a load that may range from 50 per cent to 100 per cent of the installed capacity; and with or without steam heat, if district, plant, or other heating may be guaranteed? Quickly to illustrate, take an extreme case:

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He believed it would pay every manufacturer to investigate the reliability of the public-service or local power coming to his plant and see what reserve capacity they might have, what means for transmission were available, and also whether the local company kept up inspection of its plant to produce reliability.

CHARLES H. BIGELOW thought that having the power under the control of the manufacturer meant more to him than the small saving he might effect by getting his power from a public-service station. The isolated plant, properly installed, had many points to be considered, as the power was not the only thing which was to

be used. The factory had to be heated and steam used for manufacturing purposes. The bleachery of the plant he was connected with had a bleeding turbine from which every ounce of steam was taken that was possible, and yet they had to use more live steam. In fact, the turbine was practically a reducing valve, and they were getting their electrical power as a by-product.

An isolated plant could be put in to give as good or better service than a central station, and he thought the manufacturers of northern New Jersey realized during the preceding winter what it would mean when the public-service plant was overloaded.

Wherever water power was available, he thought it should be developed and used in connection with electrical power.

No. 1657

FACTORY STAIRS AND STAIRWAYS

By G. L. H. Arnold, New York, N. Y.
Member of the Society

Considerations on the design of factory stairs containing an account of the code requirements, a résumé of the best practice and a number of suggestions in reference to the various details of construction, the selection of building materials and the manner of providing adequate illumination.

The safety of the occupants of the building, the possibility of overcrowding and the avoidance of loss of time are the factors controlling the permissible number of stairways. Main stairs should never be less than 44 in. to 48 in. between handrails. Spiral stairs and winders are objectionable in a factory; straight reinforced-concrete runs with a good fillet between tread and riser make the most satisfactory stairs. There are no special limitations in the size of the pitch, and it is possible to make a safe and reasonably comfortable stair at almost any pitch if due regard is paid to the relation of rise and length of run. All landings should be rectangular and at least as deep as the stair is wide.

In the artificial illumination of the shaft, complete distribution of the light is more important than brilliancy.

Dangerous locations of the doors leading to the stairs are illustrated and suitable arrangements are recommended.

IN the multi-story factory, the stairway is a detail worth much more than passing notice. Bear in mind that the people above the first floor are dependent on the stairs for egress; that four times daily the stairs are crowded by people in a hurry; that a large percentage of the minor accidents, many of the serious ones, and many panics happen on the stairs.

2 A poorly designed stairway may be an effective way to spread fires, smoke or false alarms and is sure to be a disturber of the heating system. A properly designed and located stairway affords not only a safe and convenient means of entrance and exit but also the handiest and most effective vantage point from which to fight fires on the upper floors.

3 In solving the stairway problem, consideration must be given to: (1) number; (2) location; (3) size; (4) type; (5) materials;

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(6) safety treads; (7) proportions; (8) landings; (9) handrails; (10) enclosures; (11) lighting; (12) wear.

1 NUMBER

4 Where building codes are in force, the minimum number of stairways permitted is usually ample. Perhaps the most usual code requirements are one stairway plus one for each 5000 sq. ft. of lot area.

5 In cases where the code provision is insufficient, and where there is no code, it is essential to consider: (*a*) safety; (*b*) capacity; (*c*) convenience.

6 *Safety.* No building over two stories in height is safe with less than two stairways. A single stairway may, at a critical moment, be blocked by a temporary disarrangement of stock or fixtures on the floor, by repairs or by fire.

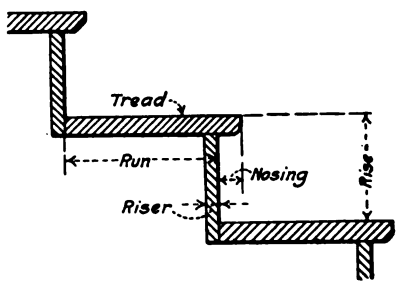


FIG. 1 THE PARTS OF A STEP

7 Large floors require an increased number of stairs even if but few people occupy the floor. As the distance of the extreme point from the stairway increases, so do the chances of floor barricades. Furthermore, in case of panic, fire or other accident, the time required to walk or carry an injured or fainting person 100 ft. or more may be enough to produce serious results.

8 Two 4-ft. stairways for buildings having up to 20,000 sq. ft. of floor area, with one additional 4-ft. stair for each additional 10,000 sq. ft., is the least number that it is prudent to use.

9 If the building is liable to be used for purposes which may permit the occupants to be closely spaced, the number should be increased to two for the first 12,000 sq. ft. plus one for each additional 6000 sq. ft. At least one and preferably all of the stairways should be carried to the roof.

10 *Capacity.* In densely populated buildings the number of

stairways must be increased to prevent dangerous overcrowding when all the occupants try to leave at once. In such cases, 20 in. in width for each one hundred persons, the Boston rule for theater exits, is high, and 10 in. to 14 in. would be ample.

11 *Convenience.* Avoiding the disturbance of discipline and the loss of time caused by the passage of people through other departments, especial arrangements on one or more floors, the need of accommodating the building to the shape of the plot, the location of exits, and the advantageous subdivision of floors among different tenants or among different departments of the same tenant, may

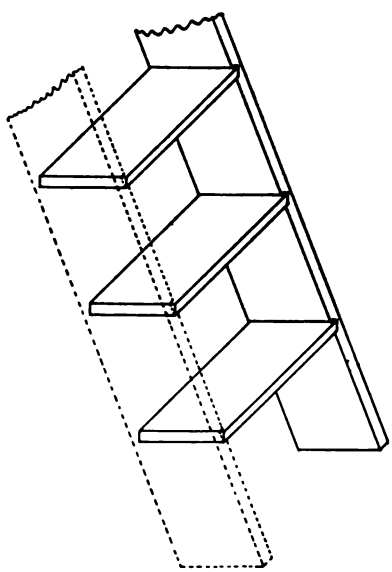


FIG. 2 STEEP FACTORY STAIRS

make it desirable to increase the number. No question of convenience should be permitted to cause stairs to be so located that any occupant of a factory would be obliged to travel over 100 ft. to reach an exit.

2 LOCATION

12 In the matter of location, many items should be considered. Every stairway should communicate directly with an exit from the building. The stairs should be distributed with a fair degree of uniformity and so placed as to reduce as much as possible the maximum distance to be traversed to reach an exit. On each floor the landing

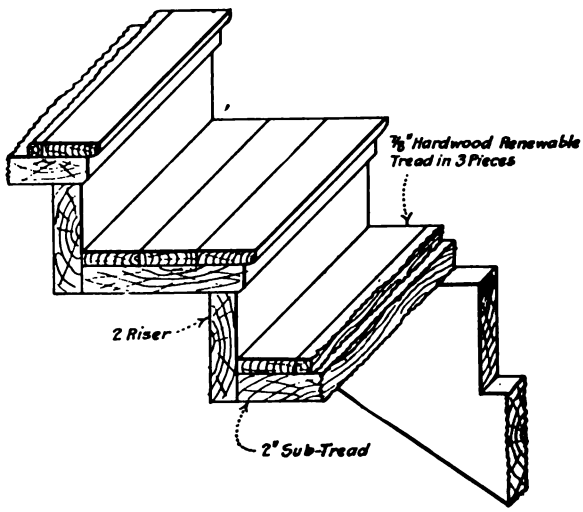
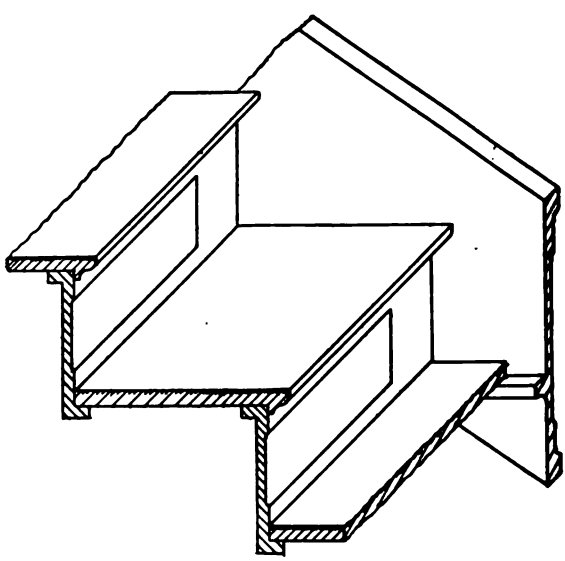


FIG. 3 WOODEN STAIRS



IG. 4 CAST-IRON STAIRS

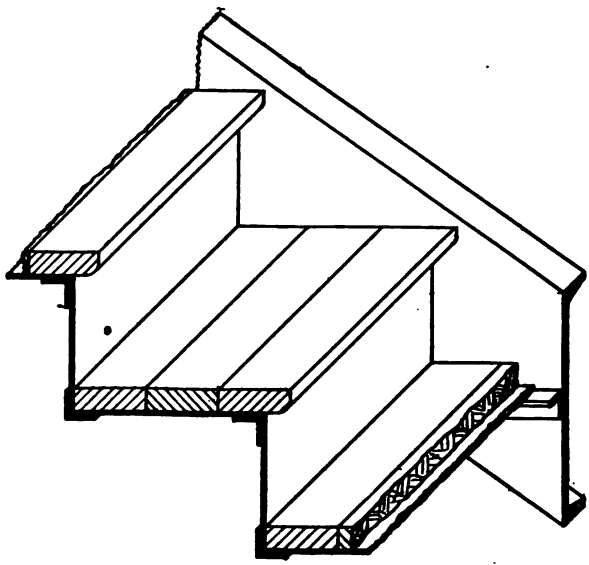


FIG. 5 STEEL STAIRS WITH WOODEN TREAD

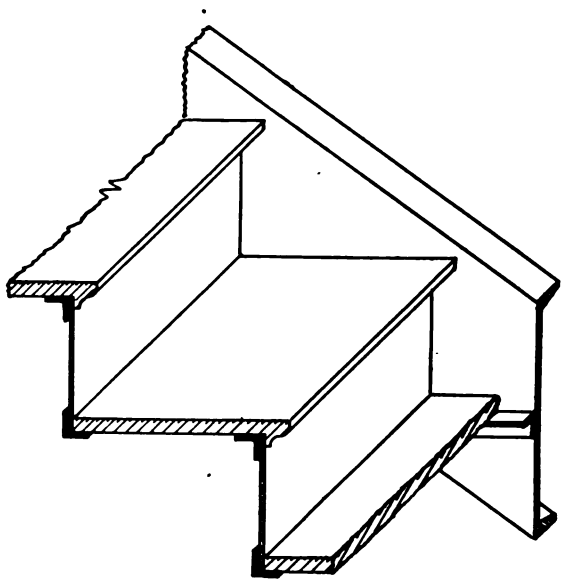


FIG. 6 STEEL STAIRS WITH CAST-IRON TREAD

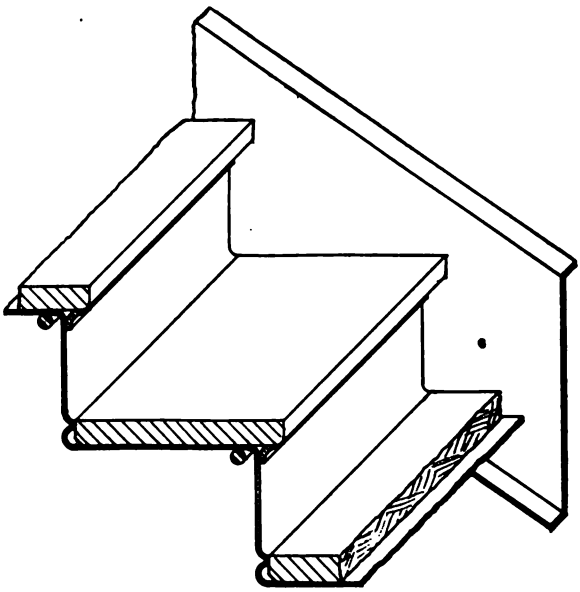


FIG. 7 STEEL STAIRS WITH STONE TREAD

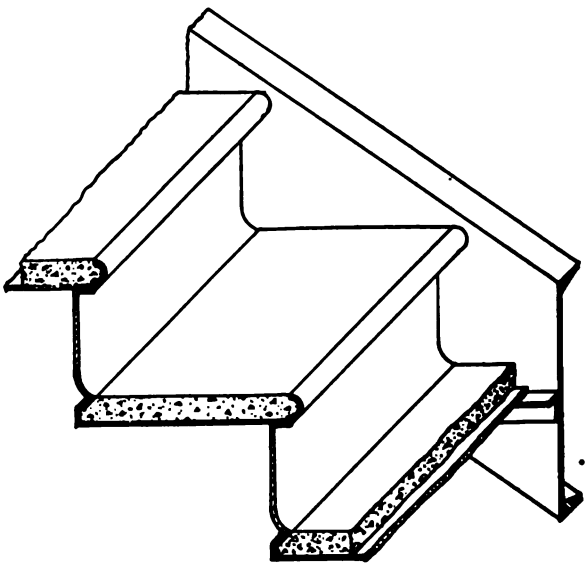


FIG. 8 STEEL STAIRS WITH CONCRETE TREAD

should be so placed that lines of men going from shop to locker room, locker room to stairs, and shop to stairs, should not conflict.

13 It is also highly desirable to avoid obstructing the foreman's view of the room. When practicable, the separate tower or wing is the most satisfactory location. The locker and toilet rooms and the elevator can be in the tower, thus leaving the main building clear of obstructions and giving the foreman an unobstructed view of the room and permitting greater freedom in the floor layout.

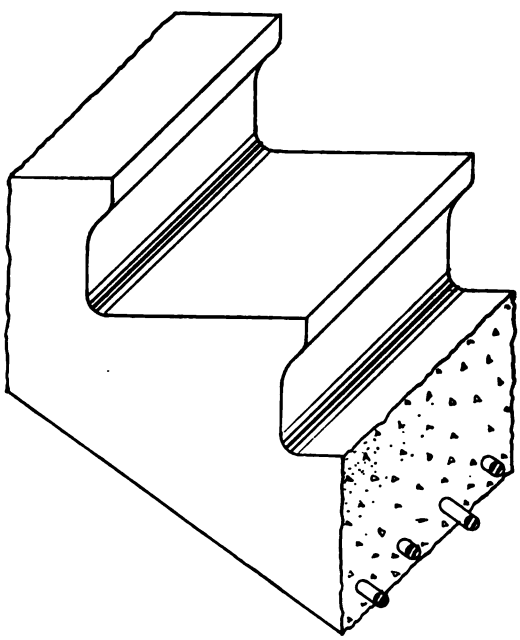


FIG. 9 REINFORCED-CONCRETE STAIRS

3 SIZE

14 A clear width of 44 in. to 48 in. between handrails will allow the passage of two lines of people at once and the main stairs should never be less than this. If wider, the width should be in multiples of 22 in. to 24 in., the number of handrails being such that it is never less than 44 in. nor more than 48 in. between rails.

15 Where the number of employees is large, it is better to increase the number of 4-ft. stairs than to increase the width. Even when the number of employees in a building is large, only one floor, as a general thing, will be densely populated. This crowded floor is as likely to be at the top as at the bottom. Therefore it is the usual

practice to make factory stairways of constant width throughout their entire length.

16 Occasionally a factory building must be designed to accommodate dense population on two or more floors. In this case, the employees from the upper floors coming down at the full capacity of the stairways will find the lower flights already taxed to the utmost and serious congestion will result. The remedy is increased widths for the lower flights.

17 Additional stairways from the lower crowded floors may not cure the trouble because, in the excitement of an emergency, when free and quick egress is most important, the occupants of the lower floors are likely to rush to the busiest stairway and leave their own special exit unused. Special stairs, not used for general ingress and egress, may be as narrow as 20 in. in clear width; they may be steep, Fig. 2, or, if not much used, they may have winders or be spiral.

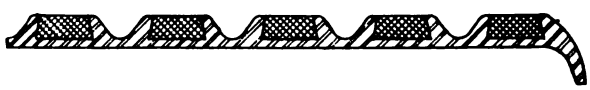


FIG. 10 SAFETY STEEL TREAD WITH LEAD PLUGS

4 TYPE

18 Except for special cases used by but few people for intra-department shortcuts, spiral stairs and winders should never be permitted in a factory. Straight runs alone are permissible. When the story height exceeds 9 ft., the flights should be cut and intermediate landings used. The landings should be rectangular and the flights should be not less than three risers nor more than 9 ft. high.

19 The intermediate landing is of little use if the flights are in line. A turn at the landing serves to limit a fall. A 180-deg. turn has the further advantage of reducing the floor space required. In fact, the stairway of minimum floor area (barring spirals) has a landing and a 180-deg. turn every 4 ft. in its height.

5 MATERIALS

20 The factory stairs are usually of wood, Fig. 3, cast iron, Fig. 4, steel or steel with wood tread, Fig. 5, steel with cast-iron tread, Fig. 6, steel with stone tread, Fig. 7, steel with concrete tread, Fig. 8, or reinforced concrete, Fig. 9.

21 The wooden stair in multi-story factories is not good practice. It is combustible and unsanitary. In buildings of mill construction,

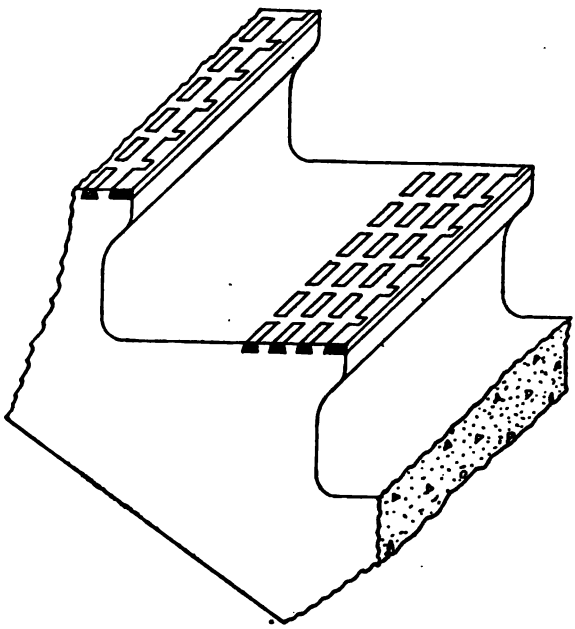


FIG. 11 LEAD SAFETY TREAD IN CONCRETE STAIRS

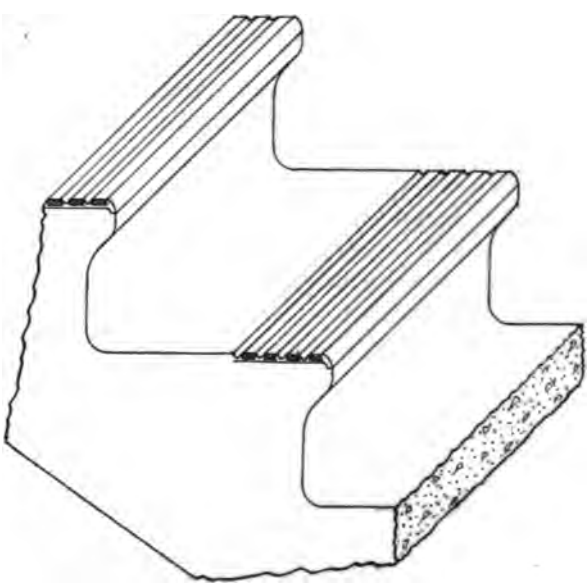


FIG. 12 LEAD SAFETY TREAD IN CONCRETE STAIRS

however, especially the smaller ones when not over four stories in height, sprinkled wood may be acceptable. The wood must be smooth, closely jointed, free from beads and not less than 2 in. thick, making a slow-burning construction. It is imperative that the wooden stairs be enclosed in a fireproof well.

22 The saving in cost, however, over a non-combustible stairway is not great enough to warrant the risk except in special cases. Cast iron and steel, while non-combustible, are not fireproof. Nevertheless, they are permissible when, as it always should be, the stairway is in a fireproof enclosure, since any fire hot enough to weaken the metals would render the stairway impassible.

23 Steel channels are more reliable for stringers and, except for short flights, cheaper than cast iron, and are more generally used. Risers are usually of angle and steel plate or pressed steel. Treads, while usually of cast iron, are frequently of checkered steel plate, wood, slate or concrete.

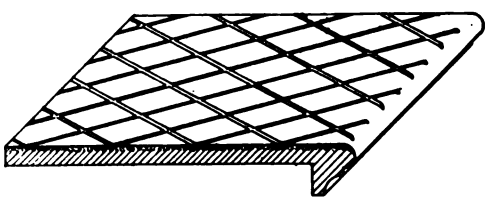


FIG. 13 ABRASIVE SAFETY TREAD

24 Cast iron and steel plate wear slippery and hence they are dangerous and should never be used without some sort of safety tread.

25 Wood, because of its imflammability, should not be used except as a safety tread over a solid sub-tread. Slate does not wear slippery but it is more expensive. It must be backed up by steel plate and replacements are expensive.

26 Concrete as a tread on steel stairs has no special advantage. The steel plate under tread is needed as it is for wood or slate, and to facilitate casting the steel is usually carried up to form a nosing. This is dangerous. The concrete is liable to crack off or wear below the top of the steel, leaving a lip over which, sooner or later, some one will trip and fall.

27 Reinforced concrete makes perhaps the most satisfactory stair if properly designed and built. There should be a good fillet between tread and riser, for sanitary reasons at least. There should be a nosing, which is not difficult to cast if made with a large fillet.

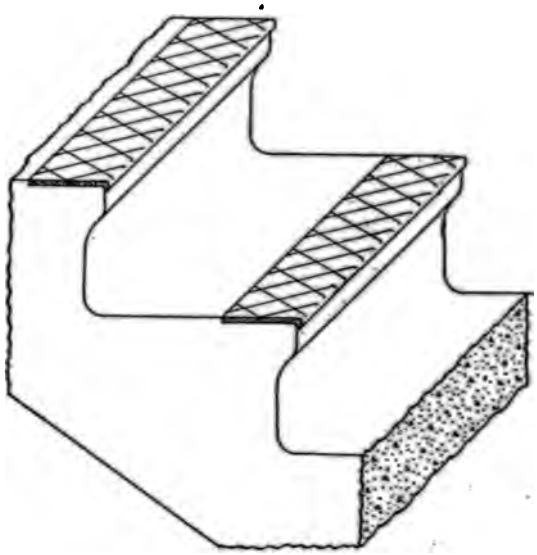


FIG. 14 ALUNDUM OR CARBORUNDUM SAFETY TREAD

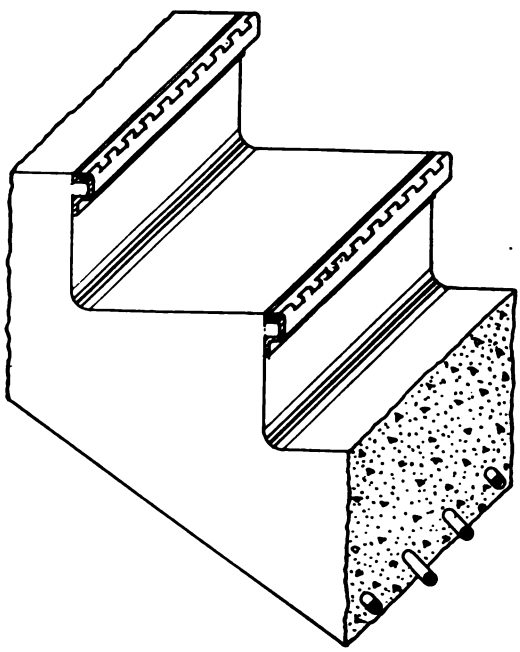


FIG. 15 ABRASIVE SAFETY NOSING FOR CONCRETE STAIRS

6 SAFETY TREADS

28 Steel, cast iron, and concrete wear slippery and so become dangerous. Consequently, some form of safety tread must be used. Safety treads are made of: (*a*) lead; (*b*) abrasive material; (*c*) a combination of the two; (*d*) cork; (*e*) wood.

29 *Lead Safety Tread.* The lead safety tread is made by inserting plugs of lead in pockets in a steel frame, Figs. 10, 11 and 12, the whole being fastened to the tread proper by screws. This of course wears more rapidly than cast iron or steel but does not become slippery and has no affinity for ice or snow. It is easily replaced when worn. The chief objections to it are that, owing to the

FIG. 16 TREAD MADE OF ABRASIVE GRAINS IN LEAD MATRIX, THE WHOLE CARRIED ON STEEL PLATE, GROOVED TOP

grooves between the lead plugs, it is difficult to keep clean, and there is some chance for a heel to catch in the grooves.

30 *Abrasive Safety Tread.* The abrasive tread is made of alundum or carborundum cast into hard metal, leaving the grit projecting slightly above the surface of the metal, Figs. 13 and 14. The

FIG. 17 TREAD MADE OF ABRASIVE GRAINS IN LEAD MATRIX, THE WHOLE CARRIED ON STEEL PLATE, FLAT TOP

abrasive is also imbedded in the rounded nosing to prevent slipping on the edge of the step.

31 This type of safety tread is made to be used as the complete tread as well as the renewable safety tread bolted to a sub-tread. It is also made as a nosing, this form being especially useful on concrete stairs, Fig. 15. This is probably the most durable tread in heavy traffic. It is, however, hard and noisy and, like the lead tread, it is difficult to keep entirely clean. There is also a chance that the grit may be too sharp, and instances are known where the shoe has been gripped so firmly as to cause a fall.

32 *Combined Lead and Abrasive Safety Tread.* A third type of safety tread is made of grains of abrasive in a lead matrix, the whole

carried on a steel plate. It is made either grooved, Fig. 16, or flat, Fig. 17, and with the anti-slip surface carried to the front edge.

33 The flat top is a great advantage as it makes it possible to keep the stairs clean. For outdoor use it shares with the lead tread the advantage that snow or ice do not adhere. It also shares with the other type of abrasive tread the danger of too acute a grip.

34 With either of the above three types of tread it is not necessary to cover the entire width of the tread. If the front edge of the step to a depth of 3 in. to 3½ in. is protected by a non-slipping surface, the remainder of the tread only needs to be brought up flush with the safety strip.

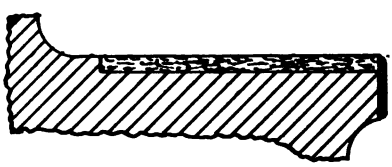


Fig. 18 Cork Tread with Metal Nosing

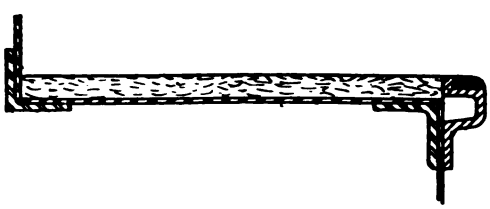


Fig. 19 Cork Tread with Safety Nosing

35 *Cork Tread.* Cork as a safety tread is not so well known nor so widely used as it deserves to be. It is impervious to almost all liquids and hence is easily kept in a really sanitary condition. It is noiseless, wears surprisingly well and is the pleasantest of all materials on which to walk.

36 Unfortunately, its lack of strength makes it necessary to use a metal or wood nosing, Fig. 18. This is not dangerous, however, because owing to the elasticity of the cork, the nosing will wear ahead of it.

37 Where stairs are liable to rough usage, as by dragging heavy pieces up or down, the cork tile is sometimes used with a nosing having a lead or abrasive non-slip surface, Fig. 19.

38 For use as a safety tread, the cork is compressed into tiles ½ in. thick by 9 to 12 in. sq. These are cemented to the sub-tread.

39 *Wood Safety Tread.* Except under the heaviest traffic, wood makes a splendid safety tread. Laid directly on top of a solid steel or concrete base and exposed only on the top and front edge, the fire risk is practically eliminated.

40 Wood offers one of the most satisfactory surfaces to step on. It is never slippery and it is cheap. The worst objection to it is from a sanitary viewpoint because it absorbs expectoration.

41 The wood should be either oak, maple or edge-grain yellow pine to wear well, the last-named being undoubtedly the longest-

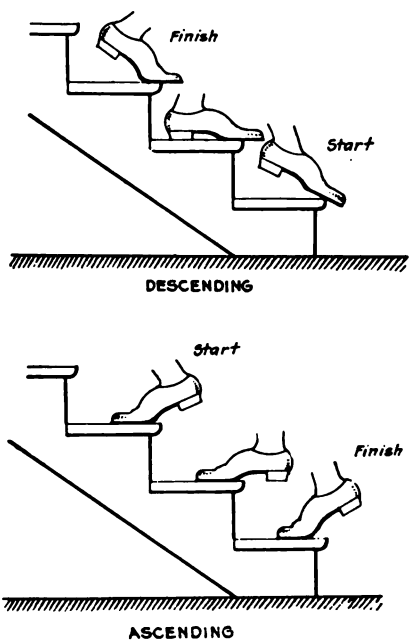


FIG. 20 DIAGRAM SHOWING HOW WORK OF ASCENDING AND DESCENDING IS CARRIED BY BALL OF FOOT

lived. Each tread should be made in three pieces, as shown in Fig. 3. The rear strip will never need to be renewed and the center strip but rarely.

7 PROPORTIONS

42 Although the pitch of stairs must be kept within comparatively narrow limits for best results, still it is possible to make a safe and reasonably comfortable stair at almost any pitch if due regard is paid to the relation of rise to length of run.

43 The natural length of steps decreases rapidly as the grade increases, even on a ramp where the surface offers equal foothold at all points. Failure to take this fact into consideration results in a stair which is awkward and tiresome, with a pronounced tendency to produce stumbling and falls.

44 The length of the foot, or rather of the shoe, is not an important factor. For one thing, the actual length of the tread exceeds the run by the amount of the nosing. For another, practically all the work of ascending and descending stairs is done by the ball of

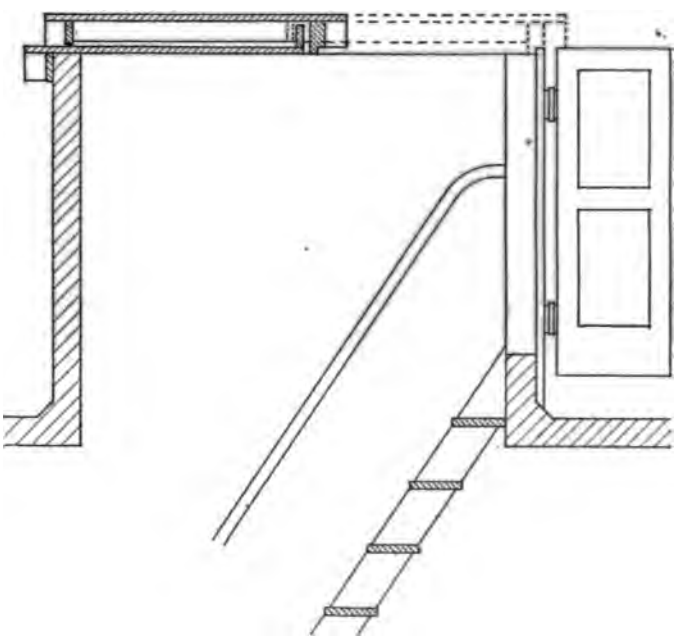


FIG. 21 PENTHOUSE FOR STEEP STAIRS

the foot, Fig. 20. In ascending the weight is borne on the ball of the foot in the middle of the step while the heel projects in the air. In descending, the toe projects, the weight being borne on the ball on, or just back from, the edge of the step, the heel barely touching the step.

45 For adults, making the length of the run plus twice the rise equal to 24 in. to 24½ in. can be relied upon to give satisfactory proportions. By this rule the rungs of a ladder should have a 12-in. spacing, which is the recognized standard, and a 45-deg. stair would

have an 8-in. rise and an 8-in. run, which a wide experience shows to be entirely satisfactory. A horizontal grating would have a 24-in. spacing, which, although a trifle short, is nevertheless within the bounds of practicability.

46 In factory practice the tendency is to make the stairs steep in order to save room. Observation by several people over a period of years and under a wide variety of circumstances confirms the opinion that an 8-in. rise by an 8-in. run is the steepest stair practicable for general use and that 7½-in. rise by 9-in. run is much better. Some building codes prescribe 7½ in. as the maximum height of rise. Although 7-in. rise by 10-in. run makes probably the easiest of all stairs, the improvement over 7½ in. by 9 in. is not usually worth the extra floor space consumed.

47 Out-of-doors stairs or steps should be made with only 6-in. rise, if possible. In any case, the rise and run must be uniform

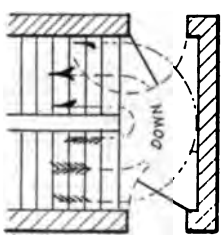


FIG. 22 DANGEROUS LOCATION OF DOORS

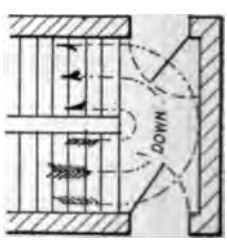


FIG. 23 EFFECT OF NARROW LANDING

throughout the entire length of the stairway. Otherwise, falls will be frequent.

8 LANDINGS

48 All landings should be rectangular and at least as deep as the stairs are wide. The surface should be of the same material as the stair treads. Attempts to save room by cutting off corners or reducing the size of landings, or by the introduction of winders or straight steps invariably result in accidents, especially when the stairs are crowded and every one is in a hurry.

9 HANDRAILS

49 Each line of people on the stairway should have a continuous, firmly supported handrail at a convenient height and of such size and shape as to be readily and securely grasped. The material may be wood or metal. If of metal, the rail will usually be iron or occa-

sionally brass pipe and of 1½-in. or 1¼-in. iron-pipe size. The 1¼-in., although somewhat small, has the advantage that the fittings are more generally carried in stock. Large sizes are used but they are objectionable as they cannot be grasped securely in the frantic effort to recover from a misstep, especially by a person with small hands.

50 T-bars and special rolled, drawn or cast handrail sections, are frequently used but, except for the architectural effect, they have no advantage over the cheap and homely wrought-iron pipe. If the rail is of wood, it should be of oak, ash or some other non-splintering hardwood; never yellow pine. It may be a round bar not less than 1¾ in. in diameter nor more than 2¼ in., or it may be one of the stock patterns carried by the mills. In any case it must be strongly supported at a height of 31 to 33 in. above the front edge of the step. Around the landing the height should be 36 in.

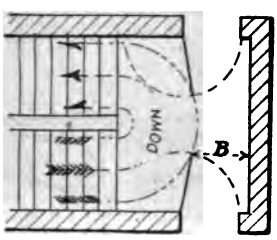


FIG. 24 WRONG SWING OF DOORS

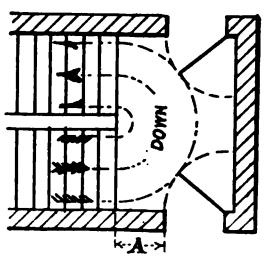


FIG. 25 PROPERLY HUNG DOORS AND CORRECT WIDTH OF LANDING

Open stairs require either a second rail at half height or a strong wire netting between stair and rail.

10 ENCLOSURES

51 Nothwithstanding the fire risk, the danger from things dropped or thrown, the chance for falls and the increased difficulty of heating, open stairways are frequently found in factories. Every stairway should be enclosed in a fireproof well. In many cities, a wire grill is permitted between stairs and elevators in the same well. A solid partition is more satisfactory and pays for the extra room and expense. Choice of material will be governed by the same considerations as in the case of the other partitions. The space under the bottom flight must be left open and kept clear unless filled up solid with non-combustible material.

52 If the stairs extend to the roof, the enclosure should be

carried above the roof in the form of a bulkhead or penthouse high enough to allow a door 6 ft. 6 in. to 7 ft. in height. If the roof flight is a ladder or a very steep stair, the penthouse may be replaced by a scuttle, or better, by a companion as shown in Fig. 21. The door or scuttle should be hooked, latched or bolted in such a way that, at any time, it can be opened readily from the inside. The roof of the stair well should be a skylight with a wire netting under the glass to catch pieces of glass in case of breakage.

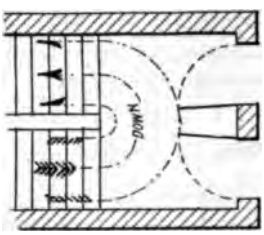
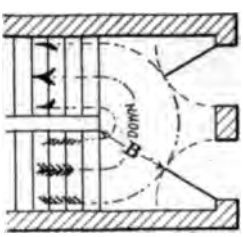
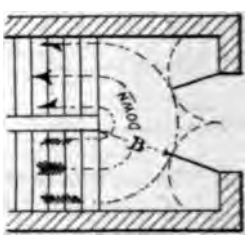


FIG. 26 WRONG SWING OF DOORS





FIGS. 27 AND 28 PROPERLY HUNG DOORS

53 At each story liberal wire-glass windows with metal frames should be provided so that the whole shaft shall be as light as may be in daylight. The better the illumination is, the fewer days in a year will artificial light be required.

54 All stairway openings should be closed with Underwriter automatic fire doors opening with the outgoing current. The outside doors need not be fire doors but should open out. Where there is much traffic, the fire doors may be supplemented by glazed double-acting doors. The locks on all these doors should be such that under no circumstances can a person be locked in.

55 Care should be exercised to locate these doors so that they may be opened without risk of crowding some one off the landing and so that a stream of people descending cannot prevent them from being opened Fig. 22 illustrates a dangerous location of the

doors. With that arrangement, a person descending might collide with the edge of the door, or if this is suddenly opened it may knock some one off the top step. In Fig. 23 the landing is too narrow, a descending crowd interferes with the opening of the door, and Fig. 26 illustrates another dangerous location. The distance *B* in Figs. 24, 27 and 28 should be not less than the width of the stairs, and distance *A* in Fig. 25 should be at least 2 ft.

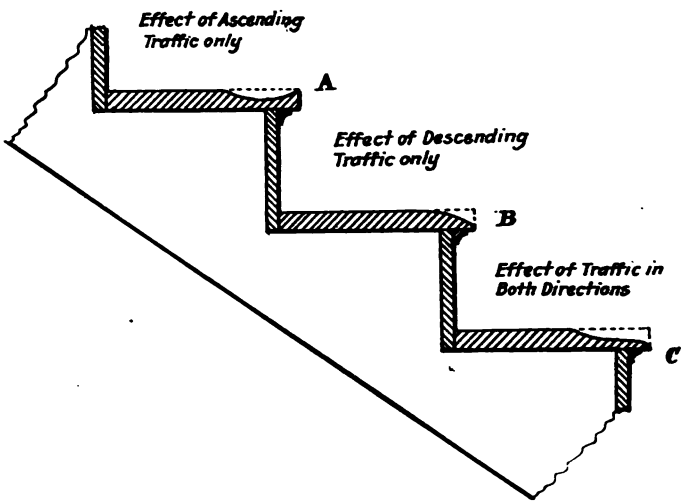


FIG. 29 CHARACTERISTIC EFFECTS OF WEAR ON STEPS

11 LIGHTING

56 In the artificial illumination of the shaft, brilliancy is not required but thorough distribution is. A light should be placed at each floor and each turn. The lighting should be in duplicate. Since there is always a likelihood of a small group of employees being in the place at night after the stair lights are out, it is quite necessary to reduce to a minimum the distance one must grope in the dark. For this reason the electric lights should have double-acting switches at each end of each circuit and the emergency lights, whether gas, candle or lantern, should be so placed that each flight can be lighted on the spot.

12 WEAR

57 Steps, subject to ascending traffic only, wear as shown in Fig. 29, at *A*. If the traffic is descending only, the wear is as at *B*. If subject to traffic in both directions, the wear will be as at *C*.

58 In any case, renewal of the front third of the tread will usually restore the worn step. At long intervals the middle third may have to be renewed if the traffic is very heavy. On wooden stairs or on metal or concrete stairs with wooden treads, the tread should be in three pieces. This will minimize repair bills.

59 Mr. F. A. Waldron, during the years 1896 to 1906, at the Yale & Towne Manufacturing Co., made extensive experiments on wooden treads constructed in three pieces as described. Hard maple, on account of its superiority for flooring, was taken as a basis of comparison. Mr. Waldron's method was to use the hard maple on every other step, putting the wood on trial on the alternate steps. Ordinary yellow pine proved to be very short-lived. Edge-grain yellow pine, on the other hand, proved to be by far the most durable, outwearing the maple two to one.

60 Where safety treads 3 in. or 3½ in. wide are used, practically all the wear will come on the safety tread and only this will need renewal. Cork treads being made in tiles 9 in. to 12 in. wide by the depth of the tread, it is necessary in case of wear to replace only those tiles which are worn.

DISCUSSION

Curtis H. Veeder (written). In 1911 we made some alterations and additions to our factory and in that connection designed a special form of concrete step with a removable wooden tread. Concrete was cast in a special cast-iron mold and in it were set cast-iron strips with T-slots in which to place the nuts of the screws used to fasten the wooden tread to the concrete, see Fig. 30. The stairs were laid out with a tread of 12 in. and a rise of 7 in., which dimensions have proved very satisfactory, as much of our product is light and is carried from one floor to another by messenger. The treads are of maple and can easily be renewed. The concrete steps were built into the 8-in. brick walls which formed the sides of the stairway.

Carl King (written). Stair treads of the materials commonly used do not present any particular hazard as regards slipping or tripping when new and under normal conditions. If the conditions could be always favorable, and ordinary stair treads were proof against wear, there would be but little advantage in equipping stairways with safety treads.

In order that there may be absolute protection from slipping, a safety tread should be so designed as to provide for direct contact

between the shoe sole and the tread surface under any and all conditions. The only manner in which this may be accomplished is by designing the tread with spaces for contact with the foot, and separate spaces wherein foreign substances may be displaced. Preferably, the tread surface should be designed with grooves or corrugations of ample size to provide channels for the drainage of water and the displacement of any substance.

To be effective, the channels should be wide and deep enough to insure a direct contact surface, and the contact surface itself should consist of anti-slip material, such as lead or an abrasive composition, imbedded in dovetailed grooves, which would remain uniform until the tread was completely worn out. Those requirements are admirably met in the type shown in Figs. 10 and 12. With this con-

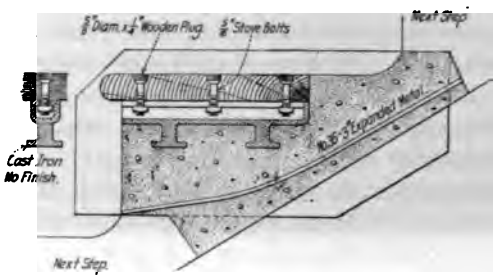


FIG. 30 CONCRETE STEP WITH REMOVABLE WOODEN TREAD

struction the lead wears no more rapidly than the substantial steel frame in which it is encased.

In the matter of cleanliness, it can readily be seen that any foreign matter dropped upon the tread or scraped from the soles of shoes can be swept to the end of the tread, which need not extend to the skirting or baseboard, and thence down the stairs; making it as easy a matter to keep the stairs clean as though there were no safety treads upon them. To my mind these facts refute the author's contention that the flat surface is an advantage in the direction of cleanliness.

IRA H. WOOLSON (written). The liberal use of wired-glass windows, as permitted in Par. 53, is a dangerous provision that should not be allowed for the sake of saving the cost of a single electric light in each story, where or when exterior window lighting is not available.

Windows in stairway-enclosure partitions should be prohibited for this reason. Even though they be approved fire windows, they are no barrier to radiant heat, and the heat transmitted through

such windows from a brisk fire in any story might easily make the stairway impassable for occupants from stories above.

Wired glass will only prevent the passage of the fire itself up to the melting point of the glass — approximately 1600 deg. fahr. That temperature may be quickly obtained from a fire in highly combustible material, especially where the opposite side of the glass would not have the protection of outdoor exposure such as would be the case in a stairway. The moment a window in a stairway enclosure, however small, is open to a fire, the whole stairway ceases to be serviceable for occupants of the building, or firemen, and there is grave danger that it will then serve as a channel for transmitting fire to other portions of the building.

The same arguments apply to the use of glass panels in stairway doors. They should be prohibited wherever possible, and if allowed at all, they should be of wired glass in metal frame, and not exceed 12 in. by 6 in. in size. This glass of such small size would not easily drop out of its fastenings when it began to soften, as usually occurs with larger sizes, and it would render service until actually melted.

Windows in exterior walls of stair shafts may be of ordinary glass, for their breaking would do no harm, and in fact this would be an advantage in case of fire, as it would allow the exit of smoke that might find its way into the stairway. A ventilator at the top of such stairways would also be an advantage for the same purpose.

Wm. T. Magruder (written). As a safety device for persons descending poorly-lighted stairways I would commend the practice of having alternate steps painted in contrasting colors or molded alternately in light- and dark-colored materials. Painting the grooves of alternate treads in white or other light-colored paint is one of the simplest and cheapest ways. It causes the user to differentiate each step from those next to it, which is not always easy to do on factory stairways. The practice makes for both safety and speed in use. It is of English origin.

H. W. Mowery (written). Many who have not followed accident-prevention work will be surprised to learn that out of 76,000 fatal casualties in a single year in the United States approximately one out of five can be traced directly to unsafe walking places and one in sixty-four to falls on stairs.

Referring to Par. 9, it is desirable that *all* stairs running through the building for exit purposes shall be carried to the roof, otherwise

people using stairs in an emergency and coming from the lower floors unaware that the stairway ended on the top floor, would be trapped.

The amount of exit capacity is a matter on which there is considerable difference of opinion. The average rate of progress of crowds of people on stairways must be known before a proper solution of this problem is obtainable. From a consideration of the results of an important study of the character of traffic and rate of movement undertaken in connection with the construction of the Hudson Terminal Building of New York, it would seem that the 10 to 14 in. of stair width per 100 persons advocated in Par. 10 is not sufficient.

Exception is taken to the statement that wood is a safety tread. Safety treads are a manufactured combination of metal, rubber, etc., and abrasive grit as the anti-slip element. It is true that soft wood presents a good anti-slip surface, but edge-grain yellow pine and hard maple mentioned particularly for such purposes in Par. 59 are unquestionably unsafe because of their slipperiness, although they may be quite durable.

So many concrete steps are built without nosings that attention is directed to the necessity for them. When descending, if there is no nosing overhang, the heel very frequently strikes against the riser, and where women are employed, their skirts are frequently pinned between the heel and riser, causing a bad fall. A nosing overhang of $\frac{7}{8}$ in. to $1\frac{1}{4}$ in. is a requisite to safety.

Treads with grooves parallel to the nosing edge are undesirable for two reasons. The series of parallel lines running in the same direction as the line of the step edge is confusing to a person descending, who is unable to distinguish clearly which one of the lines is the line of the step edge. Moreover, the presence of grooves parallel to the edge permits the toe or the front edge of the heel to catch frequently, resulting in a bad fall. A slippery nosing edge is dangerous because that is the contact point of the foot when descending.

Lead alone is not an anti-slip surface but the basis of all bearing metals used to reduce friction. A safety tread to be effective must increase the friction and must be effective even in the presence of oil and mud. An abrasive grit such as sand or ashes is often used temporarily to make safe a slippery surface. The "safe" tread, therefore, will have permanently held in it an abrasive grit; and the durability of the tread does not depend upon the abrasives, such as carborundum, alundum, etc., but upon the durability of the material by which that abrasive grit is held in place. Cement mechanically is not sufficiently strong and if an oxy-chloride of magnesia cement is used it should not be exposed to moisture, because it is soluble.

When the elements intended to prevent slipping are held in a metal frame, the metal takes all of the wear and the lead inserts act merely as the anti-slip element. After a short time, therefore, a walking surface of steel or brass edges is presented and it is very slippery, as the soft lead hollows out and leaves the hard, smooth, slippery edges in a bold relief.

Types of treads shown in Figs. 13, 14, 16 and 17 are of the abrasive-metal type. Figs. 13 and 14 are of iron with an abrasive distributed throughout the entire wearing surface at the time of casting. Figs. 16 and 17 are a lead-abrasive combination. Fig. 16 is undesirable on account of the grooves running parallel to the nosing edge, but Fig. 17 is a good type of anti-slip tread. Both the iron-abrasive and the lead-abrasive combinations are extremely durable, lasting much longer than the steel- or brass-base treads. They most nearly conform to the ideal safety tread, which should consist of "a metal matrix containing an abrasive grit uniformly distributed throughout the entire wearing surface and free from grooves or other designed variations exceeding $\frac{1}{16}$ in."

In Pars. 49 and 50 dealing with hand rails, some mention should be made of the distance from the side wall, which should be not less than 5 in. Hand rails should be placed at such a height that an individual falling forward would strike the rail with his center of gravity below it. This is particularly true of outside stairways and railings on exposed sides of a stair, and here the height should be not less than 42 in., measured vertically from the center of the tread.

ARTHUR BONIFACE[1] in a written discussion, said that a type of safety tread not touched upon in the paper was one in which alundum tread blocks 6 in. by 7½ in. by 1 in. thick were imbedded in a concrete stairway at the time of its pouring. In 1914 he had constructed a public stairway of this kind to care for a daily traffic of about 25,000 persons. After nearly four years of service test the alundum treads, which were made by the Norton Company, of Worcester, Mass., showed little or no wear, which would indicate that renewals would be unnecessary during the life of the stairway. They presented a slip-proof surface at all times, and the grip on the shoe, while positive, was not so pronounced as to hinder the momentum of the body. They had proved to be practically noiseless and easy to keep clean. They had been successfully applied also to stairways with wood treads, as well as to skeleton steel stairs.

[1] 141 West 36th St., New York, N. Y.

No. 1658

DAYLIGHT VS. SUNLIGHT IN SAWTOOTH-ROOF CONSTRUCTION

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Empirical research of the amount of direct sunlight and the intensity of daylight to be admitted on the working plane in sawtooth construction.

An equation is derived to determine the time of admission of direct sunlight and the number of hours of its duration with a given orientation of sawtooth buildings and slope of the lighting area.

Further considerations are made in regard to the influence of the size and slope of the sawtooth lighting area on the relative intensity of daylight received from the northern sky. A special example is worked out illustrating the method of computing the relative amount of diffused light entering a building.

MANY processes of manufacturing require for best results, natural illumination consisting of sufficient and well-diffused daylight, with, at the same time, however, the important limitation that little or no direct sunlight shall fall upon the working plane.

2 That is, there is a sharp distinction between daylight and sunlight and their relative desirability. The former consists of illumination by sunlight, reflected and refracted from the sky and clouds, properly designed fenestration, resulting in an evenly distributed, well-diffused light with consequent lack of sharp shadows and contrasts. The latter, or illumination by direct sunlight, is objectionable for many reasons of varying relative importance, such as the following: Its heating effect, especially in warm, southern climates; its color which has a sensation value containing a greater proportion of red rays than day light; its actinic effect upon materials used in manufacturing processes; and the fact that it is unidirectional and of excessive intensity resulting in glare, sharp shadows and contrasts.

3 *Diffusion* of *daylight* in sawtooth buildings is obtained by placing the sawteeth so that the glass or lighting area faces the northern sky; sufficient *intensity* being dependent, among other

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things, upon the size and slope of the lighting area. *Evenness of distribution* is procured by properly apportioning the lighting areas. The amount of direct *sunlight* admitted daily, the time of its admission, and its duration are evidently dependant upon three considerations, the last two of which may be varied within certain practical limits. They are:

a The day of the year, determining as it does the sun's path across the sky

b The direction in which the lighting area faces as regards the points of the compass

c The slope of the lighting area.

4 For a given lighting area, a variation in its slope is accompanied by a very appreciable change in the amount of daylight admitted, as will be demonstrated later. That is, as the pitch of the lighting area is made steeper, the amount and duration of direct sunlight entering the building is lessened, and at the expense of the general illumination. Conversely, as the slope of the lighting area is *decreased*, the intensity of daylight is correspondingly *increased*, but there also is concurrent therewith a greater amount and duration of direct sunlight.

5 The question then becomes: How steep should this slope be? What is the proper balance between the two contending requirements of little sunlight and much daylight? Also at what time of day will the direct solar rays fall upon the working plane, in what locations and volume, and for how long a period?

6 Naturally, no general answer can be given to these questions. Each individual problem should be worked out only after careful study has been made of the particular conditions and requirements which have to be met, not excluding first cost. In the Southern States, for example, the tendency is to adopt a more nearly vertical lighting area than in the northern part of the United States or Canada, on account of the greater altitude of the sun and its intense heat. Occasionally it has been found advantageous to locate machinery so as to avoid any direct sunlight during the working hours.

7 With a view, therefore, to clearing up such questions as these, the writer's firm, F. P. Sheldon & Son, undertook to work out, in conjunction with what empirical data they already had, a rational method of design for sawtooth-roof construction.

8 The subject is necessarily divided into two closely related parts, the first concerning *direct sunlight*, its amount, time of admis-

sion, duration, and location on the working plane; the second part relating to intensity of *daylight* upon the working plane.

Part 1. The Orientation of Sawtooth Buildings and the Slope of the Lighting Area as Related to the Requirements of Least Direct Sunlight

9 The amount of direct sunlight admitted daily, its time of admission and duration are dependant upon the factors given in *a*, *b* and *c* of Par. 3.

10 In the practical problem of the sawtooth roof, the effective slope or *vertical angle* of the lighting area, on account of projecting jets, gutters, and sash rails, and the interference of roof rafters, etc., is *greater* than the pitch of the glass itself. This often amounts to as much as 7° to 10°. Similarly the *horizontal angle* or bearing of the lighting area with respect to the sun's rays may be greater or less than the nominal angle on account of projecting vertical sash bars, etc. This difference often amounts to as much as 5° to 8°.

11 The position of the sun at any given time depends upon the latitude of the place, time of day, and calendar date, and may be obtained from standard altitude and azimuth tables. Knowing this, the time of admission and duration of direct sunlight for any day of the year may be calculated as follows:

12 In Fig. 1, let the plane determined by the three points, A, C and D represent the lighting-area plane, and let points A, B and E define a plane parallel with the horizon. These two planes intersect in line AF. The acute angle v is then the effective slope or vertical angle of the lighting-area plane. Also let line AB represent the horizontal direction or bearing of the sun with respect to the building at any assumed calendar date and time. That is, angle h = the difference between the sun's true bearing or azimuth and the true corrected bearing or azimuth of the lighting-area ridges, each azimuth being read easterly or westerly from north, according to whether morning or afternoon conditions are being computed.

13 Now pass plane ABC through AB perpendicular to plane ABE, cutting the lighting-area plane ACD in line CD. By construction this plane also contains the sun's altitude line through point A. Consequently, it is evident that if vertical angle x is greater than the altitude of the sun, a condition of total shade exists within the building at the given time. And contrariwise, if x is less than the solar altitude, the sun is in front of the plane of the lighting area and some direct sunlight is entering the building.

14 Now, to find x in terms of v and h (see Fig. 1),

$$AE = ED \cot v$$

and

$$AB = ED \cot x$$

and

$$\cos (90 - h) = \frac{AE}{AB}.$$

Substituting in the last equation the values of AE and AB,

$$\cos (90 - h) = \frac{\cot v}{\cot x}$$

whence,

$$\sin h = \frac{\cot v}{\cot x}$$

and

$$\tan x = \sin h \tan v \qquad [1]$$

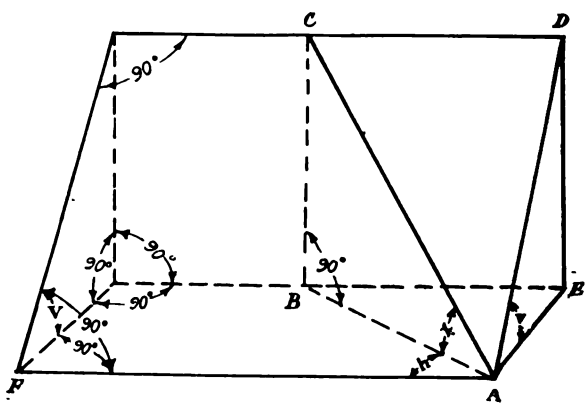

FIG. 1 TO ILLUSTRATE ADMISSION AND DURATION OF DIRECT SUNLIGHT

15 From the above equation, exact information may be obtained as to the time of admission of direct sunlight and the number of hours of its duration. The following example illustrates the method of procedure:

EXAMPLE 1. *Given*, a sawtooth building located in north latitude 36°. Orientation of building is such that azimuth of sawtooth ridges = N. 99° 08′ E. Angle of glass = 73°. *Required*, to find sunlight conditions on June 10 (sun's declination 23° N.).

16 By inspection, according to azimuth tables, sunlight will enter the building from sunrise until at least 9:20 a.m. local apparent time, because the sun's azimuth up to then is less than that of the sawtooth ridges. The method now consists in finding by trial at what time the sunlight entirely disappears from the shed.

17 Assume 10:20 a.m., at which apparent time, according to the tables, the sun's azimuth = 114° 08′ E., and its altitude 64° 46′. Now, v = 73° plus a correction for projecting jets, gutters, etc., as previously explained. (This may be found from detailed section of building and will here be assumed as 7°.) Then $v = 73° + 7° = 80°$. Also, applying the correction as explained in Par. 10,

$$h = 114° 08' - (99° 08' - 5°) = 20°.$$

Entering Equation [1],

$$\tan x = \sin 20° \tan 80°$$

whence

$$x = 62° 43'.$$

18 Since at this time the solar altitude (64° 46′) is greater than x, a small angle of sunlight is entering the shed. The above process may be repeated with a slightly larger assumed value of h, with the result that within a few minutes all direct sunlight will be found to be entirely excluded from the building.

19 To obtain afternoon conditions, the operation should be further continued until such time as sunlight is found to reënter. In this case, instead of assuming the time and computing h, the reverse method will be pursued and, as a further short cut, it may be reasoned that since the lighting area faces slightly toward the east (that is, N, 9° 08′ E.), h at the transition period will be less than in the morning.

20 The westerly azimuth of the sawtooth ridges is now used for reference with the tables and equals 90° 0′ − 9° 8′ = 80° 52′. Try h = 6°, at which time the sun's azimuth becomes (80° 52′ − 5°) + 6° = 81° 52′, the apparent time being, from the tables 4:34 p.m., and the sun's altitude being from the tables 30° 10′. Entering Equation [1],

$$\tan x = \sin 6° \tan 80°$$

whence

$$x = 30° 41'$$

21 Since x is 0° 31′ greater than the solar altitude, it is evident that no direct sunlight is entering. However, this angular difference is very slight and if the computations were carried on a step further, sunlight would be found to come in approximately five minutes later.

22 In this case then, on June 10 a condition of total shade exists within the building from approximately 9:20 a.m. until 4:34 p.m., local *apparent time*. This time is different from standard time, the proper allowance should, of course, be made. Furthermore, an additional correction must be applied in places where the daylight saving plan is in effect.

23 Generally it will be found advisable to solve a given problem for at least two sets of conditions, that of the longest day of the year (June 21, declination 23½° N.) and the average day of the year (March 21 and Sept. 23, declination 0°).

24 In the example above, it will be noted that the duration of total afternoon shade is 4 hr. and 34 min. and is considerably greater than the duration of morning shade, which is only 2 hr. and 40 min. This is due to facing the lighting area slightly, (9° 8′) toward the east, and suggests quite a range of possibilities as regards orientation.

25 By applying the principles of descriptive geometry, the amount and location of direct sunlight at any given time may be obtained, if desired, by finding the lines in which the solar rays through the top and bottom limits of the lighting area intersect the working plane — the direction of these rays being taken from altitude and azimuth tables. It may also in this case be necessary to include the effect of side walls, division walls, etc.

26 For convenience, Table 1 is presented, giving different values of x for assumed values of h as applied in the second method of Example 1. Its use makes unnecessary any reference to trigonometrical tables, unless closer results are desired, for angles not given.

Part 2 The Relative Intensity of Diffused Daylight Received from the Northern Sky as Influenced by the Size and Slope of the Sawtooth Lighting Area

27 It doubtless has been noted that, by essence, Part 1 lends itself to exact mathematical solution. This is not the case, however, with Part 2, for which, as will be explained later, the answer is not to be found so precisely on account of the necessity of introducing certain more or less arbitrary and variable factors. It should therefore be applied only with discrimination and strict regard for its practical limitations.

28 The total amount of diffused daylight entering a building through sawtooth sash and made available for use (direct sunlight being excluded) may be analyzed as consisting of:

d = light from the sky only *directly* incident upon the working plane

rd = light from the sky only *directly* incident upon the under side or ceiling of the sawtooth roof and thence being diffusely *reflected* to the room below (one reflection)

r_1c = *combined* light from the *sun and sky*, diffusely reflected from the upper outdoor surface of the adjacent sawtooth roof directly to the room below (*one* reflection)

r_2c = *combined* light from the *sun and sky*, diffusely reflected from the upper outdoor surface of the adjacent sawtooth roof, to the under side or ceiling of the sawtooth in question and thence being again diffusely reflected to the room below (two reflections).

29 The total amount of light entering the building due to the summation of the above four elemental quantities is therefore

$$L = d + rd + r_1c + r_2c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

TABLE 1 SHOWING VALUES OF (z) IN TERMS OF (δ) AND (v)

δ°	z for v = 70°	z for v = 75°	z for v = 78°	z for v = 80°
3	8° 11′	11° 08′	13° 50′	16° 30′
5	13° 28′	17° 59′	22° 18′	26° 16′
7	18° 29′	24° 28′	29° 53′	34° 38′
10	25° 30′	32° 57′	39° 24′	44° 32′
15	35° 28′	44° 01′	50° 49′	55° 44′
20	43° 15′	51° 55′	61° 05′	62° 43′
25	49° 15′	57° 36′	63° 20′	67° 22′
30	53° 59′	61° 49′	66° 59′	70° 34′
35	57° 36′	64° 58′	69° 41′	72° 56′
40	60° 30′	67° 22′	71° 42′	74° 40′
50	64° 36′	70° 43′	74° 30′	77° 03′
60	67° 15′	72° 48′	76° 12′	78° 30′
70	68° 49′	74° 05′	77° 18′	79° 22′
80	69° 44′	74° 47′	77° 50′	79° 52′
90	70° 0′	75° 0′	78° 0′	80° 0′

30 In the following derivations for each of the above four quantities, it will be noted that the individual values obtained (and therefore also the total value L) are purposely not expressed in terms of any particular standard unit of flux or intensity of illumination. On the contrary, they represent only the *relative* or *comparative* amounts of light furnished under their several respective headings. And for the analytical purposes of design, it is believed that, on account of the extreme variability of natural light from day to day and from hour to hour, the use of these values should prove to be fully as satisfactory as if they were expressed in some such term as "foot-candles" of intensity. Especially is this true in view of the fact that they may be employed in conjunction with corresponding values computed for existing buildings and of known degree of excellence as regards natural illumination.

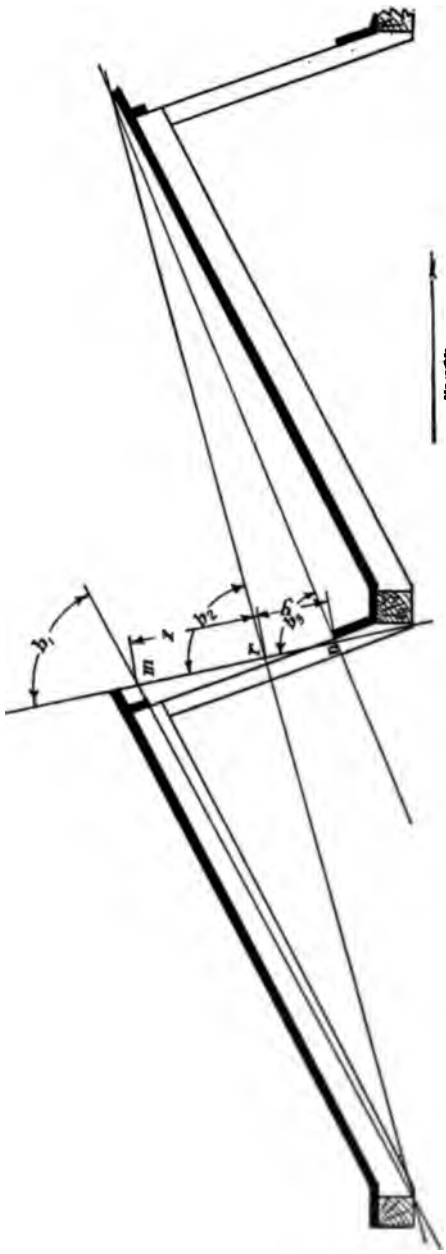

FIG. 2 TO ILLUSTRATE THE AMOUNT OF DIRECT LIGHT FROM THE SKY—d

31 However, the intensity of illumination in foot-candles could doubtless be approximated, if desired, for a given set of conditions, by applying a theoretically or experimentally determined constant, based correspondingly on the sun's position, general atmospheric conditions, kind of glass, whether single- or double-glazed, whiteness of roof, etc.

Determination of the quantity "d" or light from the sky, directly incident upon the working plane, see Fig. 2.

32 In arriving at the quantity of light represented by this heading, one of the basic assumptions is that: *The intensity of skylight upon, or the amount of skylight transmitted through, a given point in space is directly proportional to the extent or solid angle of sky to which it is exposed.* This carried a step further and accommodated to the requirements of the problem in question, reads: *The intensity of skylight upon, or the amount of skylight transmitted through, a given point or horizontal line is directly proportional to the vertical angle of the sky to which it is exposed, providing the exposures in a horizontal direction on either side of that vertical angle are equal and symmetrical.*

33 The verity of the above statement, of course, presupposes the sky to be of uniform brilliancy throughout, whereas, as a matter of fact, it is known to be brightest near the sun and near the horizon. However, in the particular problem under consideration any error due to this circumstance should be relatively small for the reason that the sky angle to which a sawtooth roof is exposed, ordinarily embraces a fair average of, and at certain times of day, practically the complete variation of, the extremes noted.

34 Now referring to Fig. 2, it is evident that the amount of direct skylight admitted by the typical construction shown is directly proportional to the sum of the total number of degrees of sky which each unit area of the "true effective area" passes, and may therefore be expressed by a summation of the product of the above unit areas and their respective sky angles.

35 By inspection, points m, r and n transmit directly to the working plane within the building sky angles b_1, b_2 and b_3, respectively, the average sky angle transmitted by all points between m and n being very closely

$$a \text{ (in degrees)} = \frac{x\dfrac{b_1 + b_2}{2} + y\dfrac{b_1 + b_3}{2}}{x + y} .$$

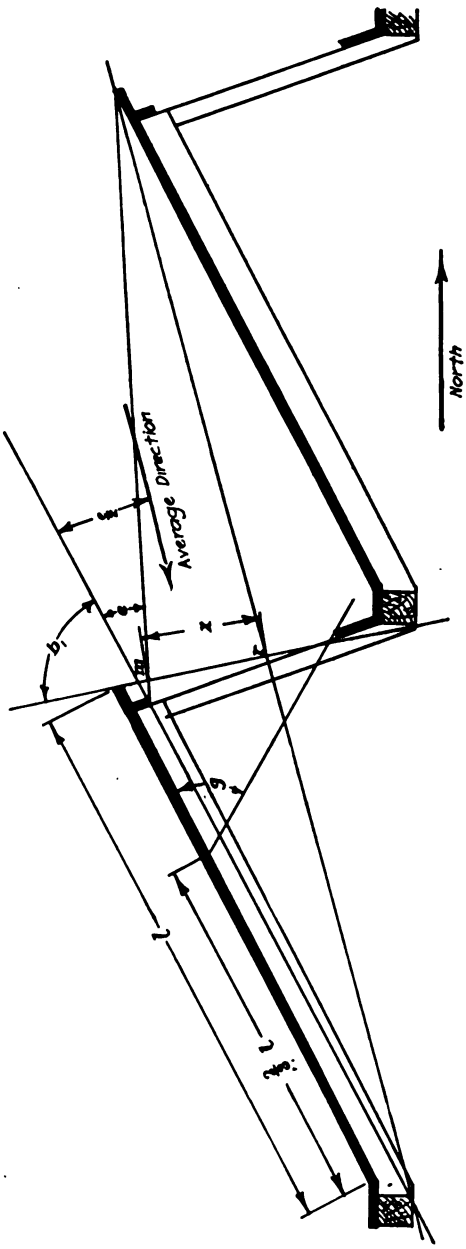

FIG. 3 TO ILLUSTRATE THE AMOUNT OF DIRECT LIGHT FROM THE SKY REFLECTED FROM CEILING—rd

36 For parallel light rays making an angle a with the lighting-area plane, the "true effective area" would be $s_{x+y} \sin a$, where s_{x+y} = area of opening in the lighting-area plane as defined in Part 1, having a height of $x + y$. But in this case, as will be seen by inspection, the angular direction of the light rays passing any point varies in respect to the plane between the average limits of zero and a. Therefore, the "true corresponding effective area" may be expressed by s_{x+y} times the average sine of this variable angle, between the limits of zero and a. This average sine by simple integration is found to equal $\frac{\text{vers } a}{a}$ where angle a is in radians. If expressed in terms of degrees as before, it equals $\frac{180}{\pi} \frac{\text{vers } a}{a}$. Whence

$$\text{True effective area} = s_{x+y} \frac{180}{\pi} \frac{\text{vers } a}{a}$$

37 Let F = the floor area in sq. ft. over which the light from area s_{x+y} is effective, that is, one span or sawtooth in length and a properly chosen assumed width corresponding to the width selected for s_{x+y}. Then,

$$d \text{ (per sq. ft. of } F) = \frac{a s_{x+y} \frac{180}{\pi} \frac{\text{vers } a}{a}}{F} \quad . \quad . \quad . \quad . \quad . \quad [3]$$

38 In computing the value of s_{x+y} proper allowance should be made for the obstruction due to vertical sash bars, etc.

Determination of the quantity "rd" or light from the sky directly incident upon the under side or ceiling of the sawtooth roof and thence being diffusely reflected to the room below. See Fig. 3.

39 By inspection, point m transmits to the under side of the roof, sky angle e and all points below m in the lighting-area plane transmit continually decreasing angles until the value zero is reached at r and below.

40 Therefore, the average sky angle transmitted between points m and r is closely $\frac{1}{2}$ e, being effective in this case over the *upper part only* of the opening in the plane of the lighting area, this portion being expressed by area s_x in sq. ft.

41 Some of this light will be absorbed by the ceiling itself, the amount depending upon the color and other surface characteristics of the latter. Let R_1 represent the coefficient of reflection of this surface.

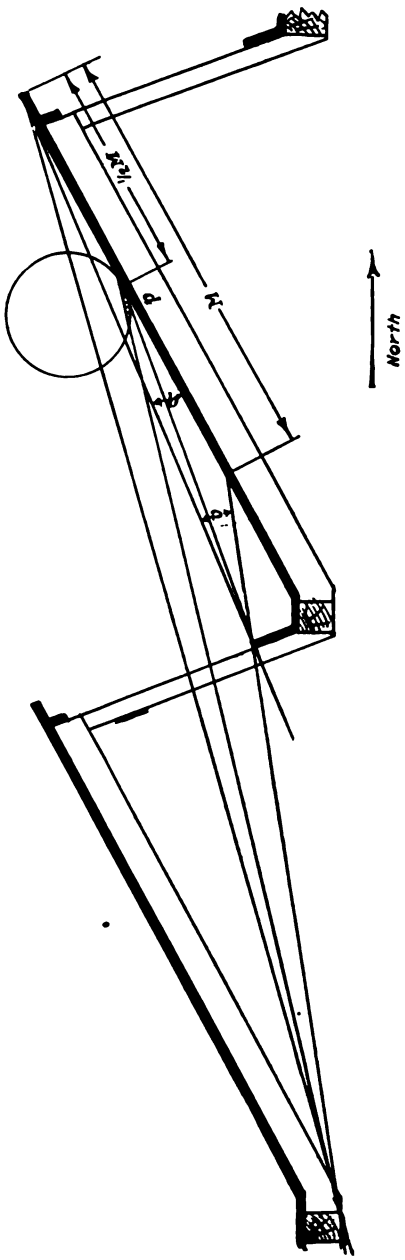

FIG. 4 TO ILLUSTRATE THE AMOUNT OF COMBINED SUNLIGHT AND SKYLIGHT REFLECTED FROM TOP OF ADJACENT ROOF — η_C

42 Furthermore, on account of the diffuse reflection from the ceiling some light is *reflected back* through the glass without being utilized.

43 For simplicity of computation the proportion of reflected light utilized to the total may be taken with sufficient accuracy as $D = \frac{180° - g°}{180°}$, since the amount of light obtained under this heading is usually relatively insignificant.

44 As e is always small the "true corresponding effective area" may be assumed with sufficient accuracy as being measured at right angles to the average direction of light rays. Whence,

$$\text{True effective area} = s_x \sin\left(b_1 + \frac{e}{2}\right)$$

Then,

$$rd \text{ (per sq. ft. of } F) = \frac{R_1 D \frac{e}{2} s_x \sin\left(b_1 + \frac{e}{2}\right)}{F} \quad . \quad . \quad . \quad . \quad [4]$$

Determination of the quantity "r_1c" or combined light from the sun and sky, diffusely reflected from the upper outdoor surface of the adjacent sawtooth roof direct to the room below (see Fig. 4).

45 The relative illumination obtained under this heading is dependant, among other things, upon the amount of light incident upon the roof and the capacity of the latter to reflect it to the interior of the building.

46 Let K represent the average ratio of the *intensity or quantity* of direct *sunlight plus skylight* incident upon one square foot of roof surface as compared with the *intensity or quantity of skylight only* incident upon and passing one square foot of lighting area s_{x+y}.

47 The relative intensity K is present over the roof area within the useful angle v of the figure. Let S_1 represent the ratio of this effective roof area to the lighting area s_{x+y}. As before, some of this light will be absorbed by the roofing itself, the amount depending upon the color and other surface characteristics of the latter. Let R_2 represent the coefficient of reflection of the roofing material.

48 The reflection of this amount, R_2, will very closely follow the cosine law of diffuse reflection, the proportional amount included within any vertical angle q from any point p being

$$\frac{q}{\pi} - \frac{\sin 2q}{2\pi} \quad \text{(where } q \text{ is expressed in radians)}$$

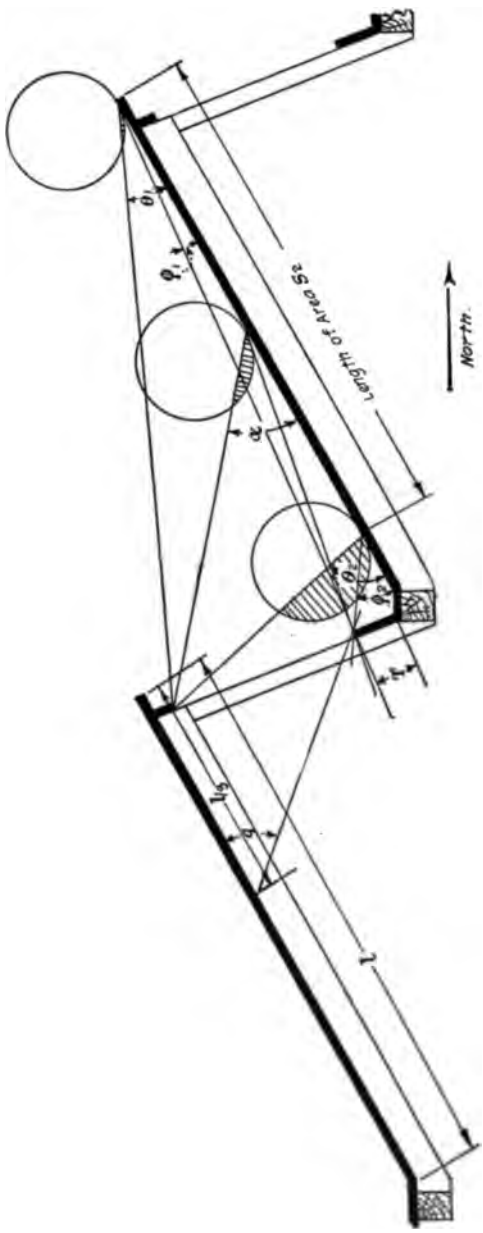

FIG. 5 TO ILLUSTRATE THE AMOUNT OF DOUBLY REFLECTED SUNLIGHT AND SKYLIGHT — r_2c

and represented graphically by shaded portion of tangent circle (Fig. 4).

49 As the amount of light obtained under this heading is usually relatively insignificant, it will be sufficiently accurate to compute the total proportional amount as

$$P_1 = \frac{q}{\pi} - \frac{\sin 2q}{2\pi}$$

50 Now, since from the previous equations, [3] and [4], the measure of the quantity of direct skylight *incident upon* and *passing* area s_{x+y} was taken as $d + \frac{rd}{R_1 D}$, then it follows that

$$r_1 c = KS_1R_2P_1\left(d + \frac{rd}{R_1D}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

Determination of the quantity "r_2c" or combined light from the sun and sky diffusely reflected from the upper outdoor surface of the adjacent sawtooth roof to the under side or ceiling of the sawtooth in question, thence being again diffusely reflected to the room below. (Two reflections, — see Fig. 5.)

51 The relative illumination obtained under this heading is also dependent, among other things, upon the amount of light incident upon the roof and the capacity of the latter to reflect it to the interior of the building. Let K and S_2 represent the ratios of light intensity and areas as explained previously, with the exception, however, that (on account of the fact that for a portion of the year the sawtooth valleys may be shaded from the sun's rays and consequently are useful only in reflecting a negligible amount of skylight) the ratio S_2 in this case should be computed for a roof area included between the sawtooth ridge and a horizontal line part way down the roof representing the average shade line on the average day of the year. This may readily be obtained by applying the principles of Part 1.

52 As before, let R_1 and R_2 respectively represent the coefficients of reflection of the ceiling and roofing material. Furthermore, the proportion of reflected light included within any vertical angle α from any point on the roof equals, according to the cosine law of diffuse reflection,

$$\frac{\alpha}{\pi} - \frac{\sin 2\alpha}{2\pi} \text{ (where } \alpha \text{ is expressed in radians)}$$

and is graphically represented by the shaded portion of the tangent circle (see Fig. 5).

53 The average value for this expression between the limits $\alpha = \theta_2$ and $\alpha = \theta_1$ is therefore

$$P_2 = \frac{\int_{\theta_1}^{\theta_2} \left(\frac{\alpha}{\pi} - \frac{\sin \alpha}{2\pi}\right) d\alpha}{\theta_2 - \theta_1}$$

$$= \frac{\theta_2 + \theta_1}{2\pi} - \frac{\sin(\theta_2 + \theta_1) \sin(\theta_2 - \theta_1)}{2\pi(\theta_2 - \theta_1)}$$

where θ_2 and θ_1 are measured in radians.

54 The above expression may be taken as the proportional amount passing the lighting area since the amount excluded between the limits ϕ_2 and ϕ_1, is usually relatively insignificant. However, this proportion may be calculated from the same formula if desired and subtracted from P_2.

55 Since the intensity of light received by the ceiling varies considerably from ridge to valley, the total useful quantity may be obtained accurately only after a more complex operation than that involving P_2 above; and for simplicity, therefore, as in computing rd, this proportion may be taken as $D = \frac{180° - g°}{180°}$. It is believed that this assumption is sufficiently accurate for the purposes of the problem, D usually representing a considerable proportion approximating 70 per cent. Therefore, following out the same reasoning as for Equation [5],

$$r_2c \text{ (per sq. ft. of } F) = KS_2R_1R_2P_2D\left(d + \frac{rd}{R_1D}\right) \quad . \quad . \quad . \quad [6]$$

56 The following example illustrates the method of procedure.

EXAMPLE 2. Given, the same typical sawtooth roof as in Example 1, having angle of glass = 73 deg.: Required to find the total amount of daylight entering — that is, quantity L, Equation [2].

First to find quantity d, Equation [3]. From the detailed building sections, it is found that

$$b_1 = 72° 30'; \; b_2 = 86°; \; b_3 = 80°; \; x = 44''; \; y = 22'';$$

whence

$$a = \frac{44\,\frac{72.5 + 86}{2} + 22\,\frac{86 + 80}{2}}{66} = 80° 30'$$

and

$$\frac{180}{\pi}\,\frac{\text{vers } a}{a} = \frac{180\,(1 - 0.165)}{80.5\,\pi} = 0.592$$

57 Let the computations be based on a section of the sawtooth

having a width of one sash, i.e., 8′ 3″, the latter having a net width of glass equal to 7′ 3″. The length of span between valleys is 17′ 0″. From the foregoing,

$$s_{x+y} = 7.25 \times 5.5 = 39.9 \text{ sq. ft. and } F = 17 \times 8.25 = 140 \text{ sq. ft.}$$

Therefore entering Equation [3],

$$d = \frac{80.5 \times 39.9 \times 0.592}{140} = 13.6.$$

To find quanty rd, Equation [4].

58 From the detailed building sections it is found as before that $o_1 = 72° 30'$; $x = 44''$; $e = 25° 30'$; $g = 40°$. Basing the computation on the same length of sawtooth as before,

$$s_x = 7.25 \times 3.66 = 26.5 \text{ sq. ft.}$$
$$F = 140 \text{ sq. ft.}$$

also,

$$D = \frac{180 - 55}{180} = 0.7$$

59 Assume that ceiling of sawtooth roof is painted white having coefficient of reflection $R_1 = 0.60$. Then, entering Equation [4],

$$rd = \frac{0.6 \times 0.7 \times 12.75 \times 26.5 \times \sin(72° 30' + 12° 45')}{140} = 1$$

which is relatively small compared with d.

To find quantity r_1c, Equation [5].

60 From the detailed building sections, it is found that $q = 15°$ $= 0.26$ radians, whence

$$P_1 = \frac{0.26}{\pi} - \frac{\sin 30°}{2\pi} = 0.004$$

61 According to a publication entitled The Sun, by Charles G. Abbott, S.M., Director Smithsonian Astrophysical Observatory, the average intensity of sunlight plus skylight on the sawtooth roof itself may be deduced as being during working hours, and for ordinary atmospheric conditions, four or five times that of skylight on the lighting-area plane. Therefore, let $K = 4$.

62 S_1 from the detailed sections is found to be 2.3. Assume the roof to be covered with clean white slag having a coefficient of reflection = 0.5. Then, entering Equation [5],

$$r_1c = 4 \times 2.3 \times 0.5 \times 0.004 \left(13.6 + \frac{1}{0.6 \times 0.7}\right) = 0.3$$

63 This quantity, represented by Equation [5], is usually so small that it may be omitted entirely from the computations.

To find quantity r_2c, Equation [6].

64 From the detailed building sections it is found that

$$\theta_2 = 80° = 1.4 \text{ radians}$$
$$\theta_1 = 24° = 0.42 \text{ radian}$$

whence

$$\theta_2 + \theta_1 = 1.82 \text{ radians, and } \sin(\theta_2 + \theta_1) = 0.97$$
$$\theta_2 - \theta_1 = 0.98 \text{ radian, and } \sin(\theta_2 - \theta_1) = 0.829$$

Therefore,

$$P_2 = \frac{1.82}{2\pi} - \frac{0.97 \times 0.829}{2\pi \times 0.98} = 0.16$$

S_2 is found to equal in this case 2.7.

$K = 4$, $R_1 = 0.6$, $R_2 = 0.5$, and $D = 0.7$, as before. Therefore, entering Equation [6],

$$r_2c = 4 \times 2.7 \times 0.6 \times 0.5 \times 0.16 \times 0.7\left(13.6 + \frac{1}{0.6 \times 0.7}\right) = 5.8,$$

whence, Equation [2]

$$L = 13.6 + 1.0 + 0.3 + 5.8 = 20.7.$$

This total quantity may be compared with corresponding values computed for existing sawtooth buildings of known degree of excellence as regards intensity of natural illumination.

65 In case additional illumination is required an alternate design having increased glass area or a flatter slope, or both, might be considered, and in this connection it is interesting to note that if the pitch is decreased by only 10°, the glass area remaining the same, L figures out to be increased by about 15 per cent. On the other hand, assuming the building placed as in Example 1 and applying the principles of Part 2, it is found that considerable sunlight will enter for the entire day. That is, the period of total shade would be decreased on June 10 from over 7 hr. to zero, or a condition of continuous direct sunlight.

66 This information, when extended to comprehend that for other days of the year, including the days of average length, and when used in conjunction with the particular conditions and requirements of the problem in question should facilitate the selection of the most advantageous design.

67 Various means have been adopted to exclude direct sunlight from the interior of such buildings and all of them seem to have the disadvantage of reducing the total illumination. Sawtooth buildings with glass vertical, that is, with the effective angle of the lighting area actually *overhanging*, are not uncommon; whitewashing the glass results in some protection against direct solar rays and a cooler interior but also in glare and considerable loss of light, the latter being

especially noticeable on dark days and when the sun is n ot shining in the shed; deeply ribbed glass produces glare.

68 Whatever glass is used, cleanliness is essential; furthermore the significance of Equation [6], indicating the possible average relative amount of reflected light, emphasizes the importance of adopting where practicable, light-colored roofing materials such as white slag, and also the use of white, dust-resisting, washable paints upon sawtooth ceilings of buildings in which maximum daylight is desired. If either of the above surfaces had been black, the average reduction in daylight for Example 2 would have been equivalent to 30 per cent, or, expressing it another way, the increased light resulting from their use amounts to over 40 per cent.

As before noted, Part 2 of the paper should be applied only with due regard to its practical limitations. It furnishes a means of comparison with known designs and is based on fair-weather conditions and with sunlight on the building as a whole. During cloudy weather the amount of useful light contributed from the top of the sawtooth roof is, of course, decreased, but, on the other hand, the quantity of direct skylight, which has been found to constitute the major portion of the total, is often thereby considerably increased depending upon the relative brightness of the clouds.

69 From the foregoing analyses it is evident that the height of valley (T, Fig. 5) for a given construction should be made as low as consistent with protection against the elements, including snow and ice. And it is a happy coincidence that in the South, where some difficulty is often encountered in obtaining the desired intensity of daylight (on account of the increased slope of the glass which it is felt necessary to adopt), the lighting area may be considerably augmented by using a shallower valley than would be considered advisable in the North.

70 Furthermore, it will be seen that for a given building, the use of a *small* number of *large*-scale sawteeth as against a greater number of *smaller* units having the same pitch, results in considerably increased daylight due to fewer number of valleys of height T, and consequently less proportionate obstruction. This principle, of course, should be applied with due regard to structural limitations and architectural considerations which may be involved, together with the important question of evenness of daylight intensity.

71 It is also worthy of note that the adoption (for the reasons above outlined) of flatter sawteeth with increasing terrestrial latitudes works out well in conjunction with the heating requirements, since it results in less cubage and radiating surface.

DISCUSSION

WM. T. MAGRUDER (written). This paper is unusual as it represents the use of the higher mathematics as a tool in architectural proportion and design and an effort at a rational method of proportioning the elements entering into the design of a sawtooth roof. One element, however, seems not to have been considered by the author, namely, the distance from the floor, or from the level of the working area, to the center of the sash and on which the evenness of distribution of illumination in part depends. Again, the pitch and the height of the sawteeth for greatest evenness of illumination are each a function of this same vertical distance. The number of variables and the assumptions which have to be made do not cause the problem to be one of easy and complete analytical solution.

When in 1907 it was decided that the new engineering laboratory of The Ohio State University should have a sawtooth roof facing the north, that the bottom of the trusses should be 22 ft. 3 in. from the floor and 16 ft. apart on centers, that the pitch of the teeth should be 30 ft., the problem of the angle of slope and the height of the glass in the north sash was solved by the university architect, Prof. Joseph N. Bradford, M.E., by the experimental method rather than by either the analytical or empirical methods. The university astronomer, Prof. Henry C. Lord, B.Sc., gave the height of the sun on June 21, and the angle of the true slope was made 16 deg. such that the direct rays of the sun do not enter the building during the working hours, or from 8.00 a.m. to 5.00 p.m. The overhang, measured normal to the glass, is 3 in. The actual slope of the glass is 18 deg. The architect made a model of the building (115 ft. by 310 ft.) to a scale of $\frac{1}{16}$ in. to the foot, having the above proportions of height from floor, pitch, glass, etc., and with the roof having three different heights of glass, and exposed a single sheet of photographic paper in the position, to scale, of 3 ft. above the floor under the entire model. The model was placed on the north side of a building, was protected from reflected light, and exposed only to the diffused light from the clear northern sky. On development this one sheet showed by the relative evennesses of distribution and the relative intensities of lighting which height of glass was preferable and gave the most uniform illumination. As the result of this experiment, the height of the slope of the roof trusses was made 9 ft. on centers for the 30-ft.

span on centers. The glass is 69 in. long, net. It starts 42½ in. from the bottom of the trusses, or 25 ft. 9½ in. from the floor. The top of the glass is 13 in. vertically below the top of the roof. The length of the incline is 8 ft. 4½ in. to the crown of the gutter. The top of the roof is 8 ft. from the crown, and 8 ft. 5 in. from the low point of the gutter. The bottom of the glass is from 18 to 23 in. above the gutter.

Those who have visited the building and seen its illumination can appreciate the success which attended this novel and original method of solving the problem.

Still another novel solution of an architectural or building problem was effected in the design of the trusses over the boiler room. This room is without columns, 46 ft. 10 in. between brick walls, and has a two-pitch sawtooth roof over it with the bottom of the Morris trusses 22 ft. 3 in. above the floor, and 48 ft. span on centers. These Morris trusses are composed of two half Fink trusses with a compression member connecting the tops or tips of the teeth of the two

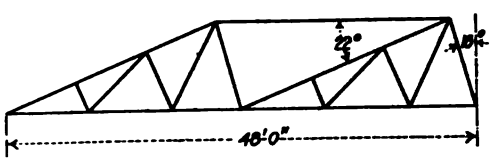

FIG. 6 TWO-PITCH SAWTOOTH ROOF TRUSS

half-trusses. See Fig. 6. The use of a sawtooth roof over a boiler room and without the use of columns is thought to have been novel at the time. It has proved that boiler rooms of this size and kind do not have to be dark and that they can be as well illuminated by diffused daylight as are shop buildings. Credit for the solution of this problem in this way is due to Clyde T. Morris, C.E., professor of structural engineering, The Ohio State University.

It is thought that this same construction could be wisely used in the design of shop and factory buildings and sheds, where good daylight illumination is a desired feature and where the absence of columns and their corresponding dead floor spaces and the greater freedom in locating machinery and aisles would more than offset the extra cost of the roof construction.

F. J. HOXIE briefly commented on the paper, saying that one advantage of the sawtooth roof which the author had not mentioned was the reflection of the heat in summer time. Nearly every summer the company with which he was connected found it necessary to shut

down for a day or two owing to the excessive sunshine, and with a white roof this could be reduced. As far as he knew, that was the only practical method of getting an equal advantage in winter.

THE AUTHOR. Referring to Professor Magruder's comments, Formula [2], Par. 29, by definition, gives the total light *entering* the building, which quantity is, of course, wholly independent of the question of evenness of light distribution. The latter element is, however, of considerable importance and may be obtained as indicated in Pars. 3 and 70 by properly apportioning the lighting areas. That is, for a given intensity and evenness of light, a low-studded building would require a greater number of small-size sawteeth or light sources than a building with a high story, although the total amount of light might be the same for each.

This problem is readily solved by the application of analytical methods not within the scope of this paper, — it being found generally advisable to adopt a ratio of span to height of center of glass area above floor not exceeding $1\frac{3}{4}$. The question of overlapping in this case is analogous to that when artificial illuminants are used for light sources. Outside the matter of evenness of distribution, story height does not affect the general result unless the atmosphere happens to be laden with dust, smoke or vapor. The use of white surfaces furthermore aids in effecting diffusion and evenness of intensity by producing reflected light (r_3c and rd) opposite in general direction to the direct illumination.

Part 1 of the paper is a matter of exact analysis and solution, but I would not have been surprised to have heard some adverse comment to the effect that the several factors in Part 2, regarding which certain assumptions were necessary, might introduce appreciable errors in the computations. In this connection, however, it should be noted that the assumptions affect only the quantity of *reflected light*, which, it can be definitely shown, amounts in general to less than 30 per cent of the total. That is, Equation [3], which expresses by far the major portion of light, is unaffected by any appreciable approximation. It will be seen, therefore, that even a considerable error in the derivation of one or all the variable factors in Equations [4], [5] and [6], governing reflected light, is greatly minimized in percentage when applied to the total. And in comparing roofs with black surfaces, this error is reduced to zero, since the last three terms of Equation [2] disappear entirely. In fact, for all ordinary computations, when comparing roofs with white surfaces, it will often be

found entirely proper to neglect these three terms altogether, if it is evident that their proportional contribution to the total will be about the same in each case. This makes the computation very simple. It is when comparing black-surfaced with white-surfaced roofs that Equation [2] in its completeness becomes of especial use in showing the effect of adopting surfaces best suited to reflect light.

The factor regarding which there seems to be the greatest lack of data at the present time is K; but of the others, S and P may be mathematically determined with considerable exactness, D with fair accuracy and R from published coefficients of reflection, regarding which there seems to be considerable and increasing information. It is hoped that more comprehensive and accurate data as to the proper average value of factor K will be established in the future. It varies, of course, with the relative slope of glass and roof to the horizon and must be estimated for each case with this in mind.

The advantage of a white sawtooth roof surface in reflecting the sun's heat, to which Mr. Hoxie refers, might easily be considerable for a thin uninsulated roof, but in the case of heavily insulated roofs (which are often adopted for example in weave sheds and dye houses to prevent condensation on the under surface) the effect would be slight. However, a reduction even of 1 deg. fahr. in some of the excessive summer temperatures often experienced within mills might well be considered worth while.

No. 1659

REFRIGERATING PLANT EFFICIENCY

By Victor J. Abbe, St. Louis, Mo.
Associate-Member of the Society

The paper deals with the conditions prevailing in the majority of ice plants and makes suggestions in regard to increasing the efficiency of their operation.

The variations of the load factor should be considered in selecting the size of boiler. High boiler efficiency depends more upon design and intelligent operation than upon the quality of fuel used.

The author condemns the practice of using a Corliss non-condensing engine for the prime mover on account of its large steam consumption when operated at fractional loads. He recommends the uniflow steam engine and the Diesel oil engine.

It should be aimed to reduce the auxiliary power to one-half horsepower per ton of ice. Wet compression is preferable to dry. Plate ice frozen from one side takes too long to freeze solid; cell-plate ice frozen from two sides freezes solid in one-fourth of the time.

Several curves illustrate the rate of heat transmission in brine coolers and ammonia condensers.

Ice storage is profitable, and with a reasonably large production of ice throughout the year it contributes greatly to the economical operation of the plant. The effects of various features of condenser installations are indicated in several curves obtained from actual cases.

The proper means to conserve ammonia are pointed out and the usual bonus systems are outlined.

THE cost of ice and of refrigeration is a composite figure of many different expenses coming under the heads of direct and indirect manufacturing expenses, selling expenses and general expenses. The cost of fuel is usually the largest item and it may easily represent the difference between profit and loss.

2 During the last two years the cost of fuel per ton of ice has doubled or trebled and many plants are now paying from $1.50 to $2.00 per ton of ice for fuel alone, and the situation is becoming still more acute because of the shortage of labor which is rapidly growing serious.

3 In spite of these conditions, and the fact that the fuel factor can be more easily controlled than any of the others, the majority

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of refrigerating plants are very wasteful of fuel as a result of improper design, run-down equipment or poor operation. While the possible savings are enormous and can usually be secured with little effort and slight expenditure, the necessity for improving equipment and operating conditions is not realized in the majority of plants.

4 It should be the aim to improve the economy of the plants from year to year by making major or minor changes and the effort for improvement should bear a relation to the cost of fuel and labor.

5 The ideal plant is the one whose manufacturing cost is constant in spite of the great increase of costs. The practice of "sapping" a plant, that is, getting out all the possible profits without reinvesting any, has made many a plant valueless.

6 Fuel cost, while most important, is not all-important, however, and there are ice plants having a very high fuel economy that are losing money. A high efficiency must be maintained generally in the design of the plant, in its load factor and in its labor and sales organization. There are far more plants making on the average, per year, 1.5 to 2.5 tons of ice per ton of fuel than plants making 5 tons, having simple non-condensing plants in mind.

7 Fig. 1 is submitted as an illustration of the performance of a number of plants taken at random, showing both their yearly output and the ratio of tons of ice made per ton of coal. For example, the plant shown as having the least capacity is one of 2000 tons per year and makes 2 tons of ice per ton of coal.

8 In this paper the writer will express himself frequently in terms of tons of ice per ton of 10,000 B.t.u. fuel, an expression which tends to equalize the value of the various fuels (semi-bituminous, bituminous, lignite, oil, etc.), since by a simple recalculation it places them on a common basis.

BOILER ROOM

9 If the refrigerating plant is steam-driven, careful thought must be given to the boiler room: to proper selection of fuel, boilers and proper installation and operation. The average boiler room is very wasteful due to conditions in the furnace and boiler, to the excess air, incomplete combustion, scale and soot.

10 With waters that have a tendency to prime, it is often the practice to underload the boilers so as to prevent priming. In a certain plant having Stirling boilers and using water containing 80 grains of chlorides per gallon, serious trouble was experienced with

priming until the steam connection was changed to the rear drum, after which it was possible to operate the boilers with water having a large amount of salt without any priming developing. In the same plant scale caused by calcium sulphate was overcome by adding sodium hydroxide to sodium carbonate and lime treatment.

11 As the load factor of most refrigerating plants varies greatly, the boiler installation should be such as to give flexibility of operation. In small plants arrangements should be made to reduce the grate surface during the winter periods; each boiler

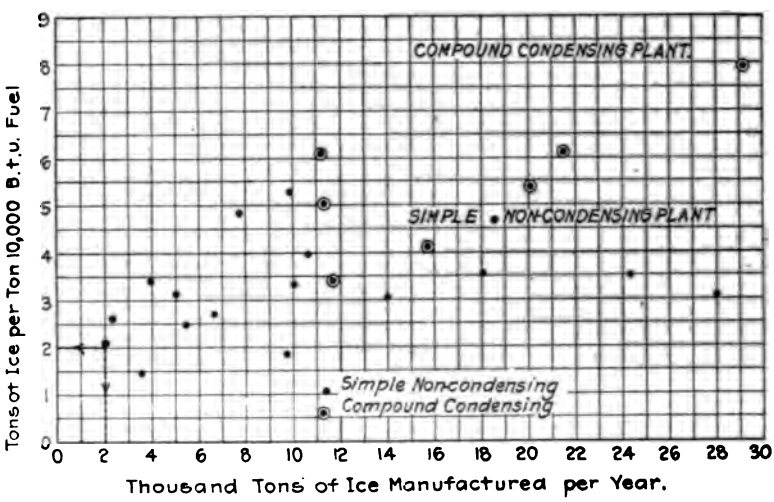


FIG. 1 ACTUAL AVERAGE ANNUAL RESULTS OBTAINED BY ICE PLANTS

must be equipped with a draft gage and the draft should be maintained at the minimum required and varied with the load.

12 The boiler setting should be high, even with return tubular boilers, with a space of from 4 to 5 ft. between grate and boiler shell, and the combustion chamber should be so arranged that the benefit of this increased space is obtained. Gases tend to take the shortest path, and with most of the combustion-chamber space devoid of drop walls there will be circulation of the gases and many eddy currents or dead spaces.

13 The gases should flow slowly until they reach the heating surface, where combustion should be complete. After this the velocity should be high so as to allow greater heat absorption. Some of the boilers on the market were designed upon more or

less crude engineering principles and, although good steam producers, they are not economical.

14 As far as fuel is concerned, it must be said that any fuel can be burned if proper provisions are made — shavings as well as oil or semi-bituminous coal. The selection mostly depends upon cost and availability. Lignite, for example, is a most excellent fuel for localities such as Texas. With Texas lignite burned under return tubular boilers efficiencies were obtained of from 63 to 68 per cent. The composition of the lignite was as follows:

Moisture	21.5 per cent
Volatile matter	42.31 per cent
Fixed carbon	24.08 per cent
Ash	12.11 per cent
B.t.u. dry	9530
B.t.u. actual	7850

15 With chain-grate stokers and Texas lignite, and an equivalent evaporation of 5.64, a boiler efficiency of 67 per cent and a boiler overload of 15 per cent were obtained. With Colorado lignite, boiler efficiencies of 70 per cent were frequent. Wood, such as slabs, when obtainable, can be burned quite well, only the furnace must be of proper design with two sets of fire doors, one above the other.

16 Higher boiler efficiency is not so much dependent upon the quality of the fuel as it is upon the design of equipment and intelligence with which the fuel is fired. With the highest grade of semi-bituminous coal the writer witnessed tests giving an efficiency of 50 per cent, and 70 per cent with the low-grade lignites. Economizers are very valuable and bring excellent returns upon the investment. Even with load factors as low as 35 per cent and a 15 per cent fixed and operating expense, a yearly saving of 30 per cent of economizer investment will be made, based upon fuel at $2.50 per ton of 10,000 B.t.u. and normal economizer prices. At the present economizer prices are, of course, abnormal, and so is also the cost of fuel. Emphasis has repeatedly been laid on the importance of equipping ice plants with proper boiler-room instruments.

PRIME MOVERS

17 The prime mover most generally used in refrigerating plants is the Corliss non-condensing steam engine. Next in order are the compound Corliss, electric motor, oil engine, and uniflow

steam engine. If this order were reversed, however, enormous sums of money would be saved to ice manufacturers, for the following reasons:

18 In selecting the prime mover for an ice plant, the two most important items to consider are efficiency at rated load and efficiency at half load. While the average Corliss non-condensing engine con-

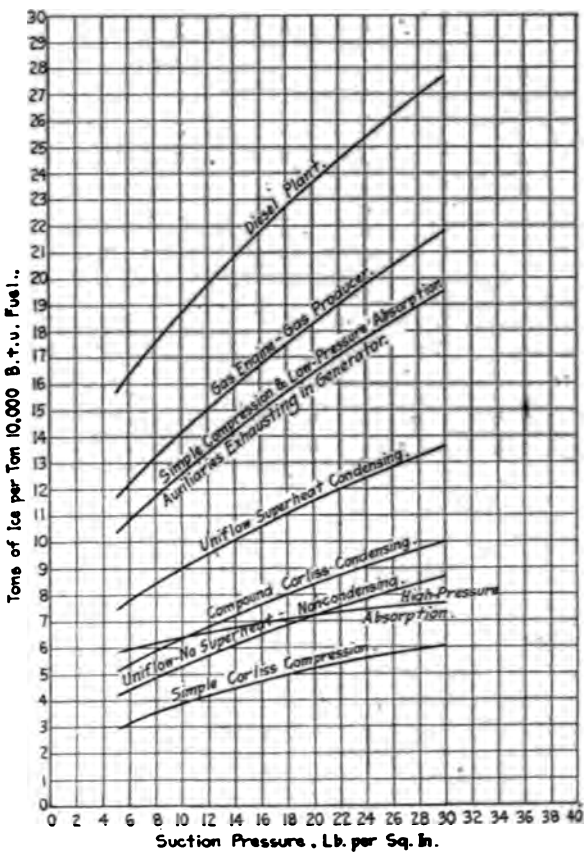


FIG. 2 RELATIVE EFFICIENCY OF VARIOUS ICE-PLANT INSTALLATIONS

sumes 20 per cent more steam at half load than at full load, the uniflow engine uses only about 8 per cent more. This is of great importance because of the great variations of load factor. Many engines can be found operating at one-eighth cut-off. This is the reason, also, why a steam cylinder should be adapted to the back pressure at which the compressor operates. It is most unwise to

have a steam cylinder large enough for economical cut-off at 25 lb. suction pressure when the pressure to be maintained is 15 lb. or less.

19 Fig. 2 shows the results to be expected from various types of installations. The allowance made for auxiliaries ranges from one-half to one-horsepower per ton of ice, depending upon conditions. The condenser pressure was taken at 185 lb. gage, and it was assumed that at the suction pressure given the machine would operate at about full load.

20 In small plants preference should ordinarily be given to the use of superheated steam, since as high an economy may be obtained from a uniflow non-condensing engine operated with superheated steam as from a compound Corliss condensing engine using saturated steam, and the former equipment is a great deal simpler and necessitates less auxiliary power. Furthermore, the steam-consumption curve is flat and the high efficiency of the plant will be maintained during the winter time.

21 Superheaters can be installed with facility even in existing installations, and since the gain is greater with simple non-condensing engines, uneconomical ice plants will derive great benefit.

22 In the majority of ice plants the initial steam pressure in the steam cylinder is from 70 to 90 lb. Even in plants having high-pressure boilers the benefit to be derived from high-pressure steam is not usually taken advantage of. Tests show an economy increase of 7.5 per cent by raising the pressure from 75 to 100 lb., and of 4 per cent by raising it from 100 to 125 lb.

23 In order to gain in economy, a simple engine is often made to operate as a condensing engine. As a result the temperature difference in the cylinder is increased and the cut-off is shortened, which increases the wall area at cut-off as compared to volume. This greatly increases cylinder condensation, which is directly proportional to the temperature difference and the area exposed. It therefore seldom pays to operate such a machine at more than 20 in. of vacuum, and if the plant is to be changed over to condensing operation, it is best to replace the simple Corliss by compound cylinders or by a uniflow engine and leave the rest of the machine intact.

24 Under proper conditions the ideal and most efficient prime mover for the ice manufacturer is the Diesel oil engine. By "under proper conditions" is meant conditions of oil supply and cost, and kind of operating force to be employed. It cannot be over-empha-

sized that with the Diesel engine a high-grade engine-room force must be maintained, especially during the overhaul period. If the men in charge are intelligent, the Diesel engine is a very dependable unit. There is a plant in California that produces a ton of ice for 5 gal. of fuel oil, and this not under the best conditions. There are oil-engine installations on record, not necessarily Diesel engines,

TABLE 1 DIESEL POWER-PLANT PERFORMANCE

	Total	Per net Kw-hr.
Wages paid	$4545.10	$0.00405
Fuel-oil consumption	3416.49	0.00305
Lubricating oil	466.86	0.00042
Repairs and supplies bought	1116.50	0.00100
Repairs and supplies, home work	1367.49	0.00122
	$10912.44	$0.00974

MONTHLY RESULTS

Month	Total Power Generated, Kw-hr.	Total Power for Auxiliaries Kw-hr.	Net Power Generated, Kw-hr.	Fuel Oil Consumed, Gal.	Cost of Fuel Oil per Gal., Cents	Gal. of Fuel Oil per 100 net Kw-hr.
April	65770	7176	58594	5141	3.63	8.774
May	95270	10712	84558	8142	3.63	9.629
June	119340	13785	105555	10671	3.61	10.109
July	132150	14482	117668	10843	2.9	9.215
August	131540	16275	115265	12593	2.65	10.925
September	114840	12973	101857	10125	2.33	9.94
October	114120	12567	101540	9431	2.31	9.288
November	110160	12737	97423	9459	2.56	9.709
December	113330	12159	101071	9660	3.00	9.558
January	86640	11213	75427	7220	3.13	9.572
February	84490	9489	74991	6993	4.5	9.325
March	128570	14413	114157	11175	4.5	9.789
April	100350	11656	88694	8766	7.0	9.883
May	108950	12871	96079	9232	6.15	9.605
June	176000	19100	156900	15488	6.15	9.871
July	168490	17333	151167	14946	4.25	9.89
August	150890	18652	132238	13569	4.25	10.261
September	90450	11029	79421	8052	4.5	10.138
October	61700	8201	53499	5591	4.87	10.45
November	42540	5867	36673	4076	4.87	11.114

that have given a ton of ice for less than 10 cents fuel cost, with oil at 2 cents a gallon.

25 Table 1 gives the average results obtained with Diesel engines over a long period. The net work produced was 1,119,801 kw-hr. The auxiliary power represented the power required for injection, in the air compressor, and in the water-jacket circulating

pumps. The load factor having been highly variable, the results are not quite as good as they otherwise would have been, consequently the figures may be taken as being rather conservative and dependable.

26 Diesel-engine manufacturers have somewhat neglected the private buyers lately, from the fact that they were putting every ounce of their energy into Government work, but after the war Diesel installations and their modifications ought again to be rapidly on the increase.

27 In a great many localities electric power can be obtained quite cheaply and when this is the case electric drive is to be favored. The main advantage of an electric installation is that high efficiency can be obtained through the whole load-factor range and that economy increases as the load factor drops, contrary to the condition found in steam-driven ice plants.

28 Induction motors are not very well adapted for ice-plant work because of the high speeds required for high efficiencies. Synchronous motors, on the other hand, have characteristics that make them ideal, even for direct connection to refrigerating machines. Their efficiency curve is quite flat and their efficiency is rather high at part loads.

29 An electrically driven raw-water plant is a great deal simpler than a steam-driven plant. Many factors which influence plant efficiency are eliminated and consequently the operating man does not have to be as high grade as for the efficient operation of steam plants. Labor cost and repair expenses and the cost of real estate, buildings and machinery are all less. Dependability is also fair and with proper installation as good as in the case of a steam plant.

AUXILIARIES

30 The curse of most ice plants is the auxiliaries. In many cases the steam consumption of the auxiliaries is as great as that of the engine running the compressor. In a certain ice plant of 100 tons capacity the following auxiliaries were found in operation: Electric-light engine; duplex circulating pump for ammonia condenser; duplex circulating pump for steam condenser; duplex brine pump; duplex boiler-feed pump; ice-hoisting compressor; single-stage single-steam-cylinder deep-well compressor; agitator engine and cooling-tower fan engine. In this plant the steam consumption of auxiliaries as compared to the compressor engine was as 60 to 40 and the plant was making about two tons of ice per ton of fuel. It

is not so much the *number* of auxiliaries, however, as their selection from the point of economy and the arrangement under which they operate.

31 It is hard to state definitely how many auxiliaries are needed, since each plant must be considered separately in this respect. At times it may be better to operate two pumps than one; and at times the addition of one or two auxiliaries might produce a substantial overall saving. The trend, however, is generally toward too great a number of uneconomical auxiliaries, frequently either too large or too small for their work and poorly designed in other respects.

32 The standard requirements for auxiliary power per ton of ice produced should be 0.5 hp. and every effort should be made to keep down to this figure. In some plants the auxiliary power far exceeds 1 hp. per ton of ice, and if we take into consideration that this 1 hp. is produced by most uneconomical means, we realize how important it is to keep it down to a minimum.

33 The idea of driving the auxiliaries of an ice plant from the main engine shaft is not a bad one and this method is quite dependable if the belt transmission has been installed in a workmanlike way. At light loads especially this arrangement should be very profitable, but is to be considered only, in the smaller plants. Such plants ordinarily operate with wasteful duplex pumps and small throttling slide-valve engines, and by keeping these in reserve and pumping water by centrifugal belt-driven pumps a saving as great as 30 per cent can often be obtained. In designing a new plant or overhauling an old one, most careful consideration should be given to reducing to a minimum the head against which water is to be pumped.

34 One of the most uneconomical auxiliaries as usually operated is the air lift. This statement is meant as no reflection upon the air-lift pump as such, but on the way in which it is usually operated. Fig. 3 shows the performance of properly designed air lifts; the efficiency decreases somewhat as the lift increases, but should not be less than 60 to 80 per cent, whereas, actually in some cases it will be found as low as 20 per cent; the trouble is usually too great or too little submergence.

35 It is seldom advisable to use an air-lift pumping system for the circulation of water over the steam condenser, because of the increased head required. The use of a cooling tower is ordinarily to be preferred and any water needed for make-up may be taken

from the air-lift system and passed over the distilled-water and liquid-ammonia coils, thus cooling the latter below the temperature of the circulating water proper.

36 For driving auxiliaries, electric current from generators driven by uniflow engines is to be preferred in the majority of installations and the various units must be selected with a view to obtaining a flat efficiency curve between half and full loads; all motors on the larger units should have variable speed control.

37 Duplex steam pumps or steam-driven deep-well pumps should not be used except possibly as a reserve. While they may be desirable where they are to operate only a small part of the time,

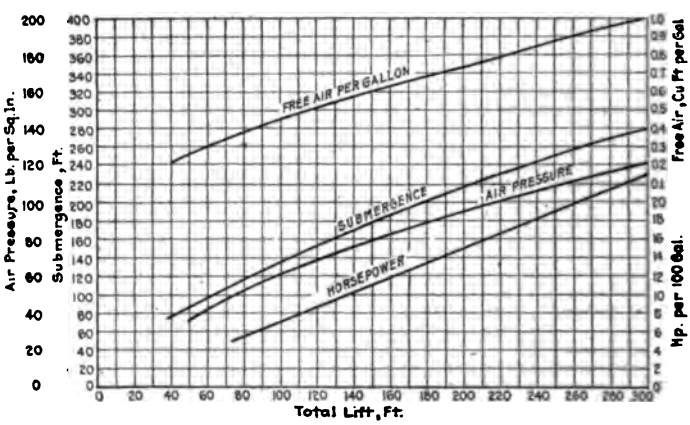


FIG. 3 STANDARD AIR-LIFT PERFORMANCE

this is not the case in a refrigerating plant which, in spite of its variable load factor, ordinarily operates the year round. Their efficiency curve also drops off rapidly when the load is reduced.

ICE TANKS

38 All the details incidental to the process of ice making should be so regulated as to secure a high rate of heat transmission, coupled with a low temperature difference. The ice tank is a most important member of the ice plant, and in the discussion which follows three systems will be considered: ice frozen from one side; plate ice frozen from two sides; and can ice.

39 Plate ice frozen from one side is not to be recommended, even though it is true that very good ice can be made by this system, because it takes six days to freeze the ice blocks which are

commonly 11 in. thick, and high suction pressures are entirely out of the question. Further, one tank space with plate ice will have to be three times as great as with can ice owing to the freezing time being three times as long. Also, when the plant is operating at light load, the suction pressure will rise and cause the ice to freeze unevenly — too thick at the bottom and too thin at the top.

40 The second system mentioned — of freezing plate ice from both sides — has recently been developed and patented and is a decided improvement over the first method of freezing from one side only; and from an economic standpoint it is even a considerable

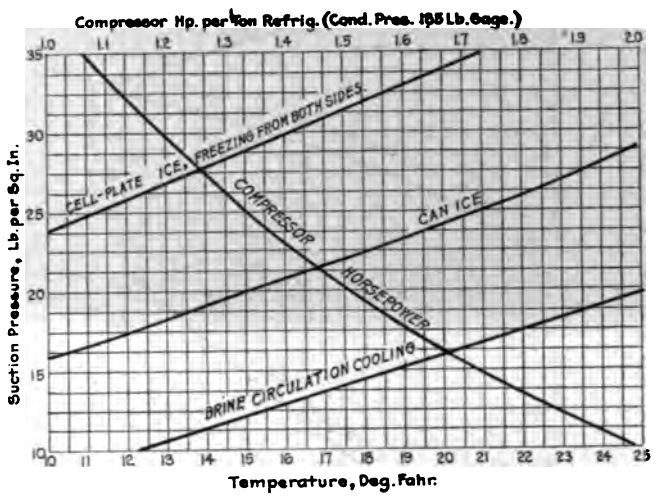


FIG 4 BACK PRESSURES OBTAINED WITH CELL-PLATE ICE, CAN ICE AND COLD STORAGE COOLED BY BRINE CIRCULATION

improvement over the can-ice system. By freezing from both sides the ice will be frozen in one-fourth of the time with the same temperature difference between the evaporating ammonia and the ice. This ice is very uniform and fully as good as raw-water can ice. The economic possibility of this system over can ice is due to its elimination of brine and the consequent reduction of the total temperature difference required. The back pressure obtained with "cell-plate ice," as the above should be called, and with can ice, also with cold storage cooled by brine circulation, is represented in Fig. 4, where the curves are based on a 10-deg. temperature difference between the ice and the refrigerating agent in each case.

41 Taking up the can-ice system, Fig. 5 shows the influence of thickness of ice block upon plant economy. For several reasons, chiefly convenience of handling, a 300-lb. block is almost universally adopted. Such a block has, ordinarily, an average thickness of 11 in. and its freezing time is 48 hours with 14-deg. brine. On the other hand, a block having a thickness of 8 in. would freeze in only 24 hours. In addition to the greater freezing rate with thinner ice, there is also more can surface per ton; as for example, for a given weight of ice a 150-lb. block 8 in. thick will have 30 per cent more

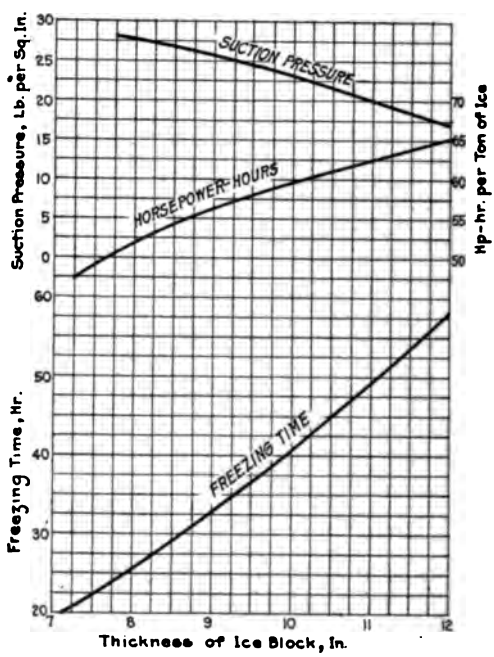


FIG. 5 EFFECT OF THICKNESS OF ICE BLOCK UPON PLANT ECONOMY

can surface than a 300-lb. block 11 in. thick. By this is not meant that 8-in. ice is advocated; it is only mentioned to show the effect of ice thickness. One of the objections to ice of this kind is the greater exposed area and consequently greater shrinkage loss during the delivery period, which, however, can be overcome. As far as handling is concerned, great improvement can be made. In a certain plant in St. Louis it was arranged to hoist a row of eighteen 200-lb. blocks by one operation and the blocks were all thawed and dumped at the same time.

42 Circulation of the brine in the freezing tank is also a very important item in economical ice-plant operation. This circulation is at times produced by centrifugal pumps, but ordinarily by propeller agitators. Often these agitators are very inefficient and tend more to churn the brine than to circulate it. It is ordinarily difficult to determine what the circulation in an ice tank is, due to the fact that the speed of the brine varies and its velocity in the lower part of the tank is not the same as in the upper part. About the most

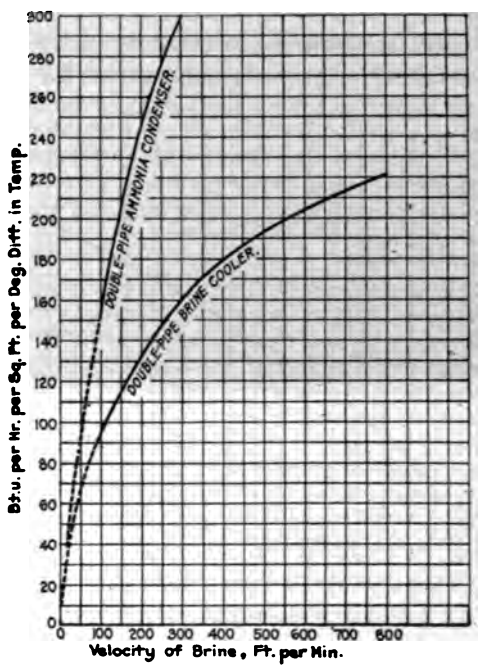


FIG 6 HEAT TRANSMISSION WITH DOUBLE-PIPE BRINE COOLERS AND AMMONIA CONDENSERS

practical way is to measure the difference in the height of the brine in the tank on the suction and discharge sides of the bulkhead close to the agitator. With tanks as ordinarily constructed, 1 in. difference of level for each 10 cans of tank length is assumed by the writer as a standard. This method should be fairly accurate since brine flow is the result of difference in level.

43 In agitating the brine, its level should never be below the level of the water in the can. Too low a brine level will greatly

reduce the capacity of the tank and also the plant efficiency. A wide, shallow hole in the top of the block toward the end of the freezing period is always an indication that the can is too full or the brine too low.

44 Since with long tanks or very strong agitation, considerable brine level difference is produced, in some cases as much as 5 in., it is best to construct long ice tanks with agitators on each end. Brine velocity is helpful in two ways; it increases heat transmission between the brine and the can, and between the evaporating coil and the brine.

45 The average transmission of heat from the ice in the can to the brine outside is very poor, only about 2.5 B.t.u. per deg.

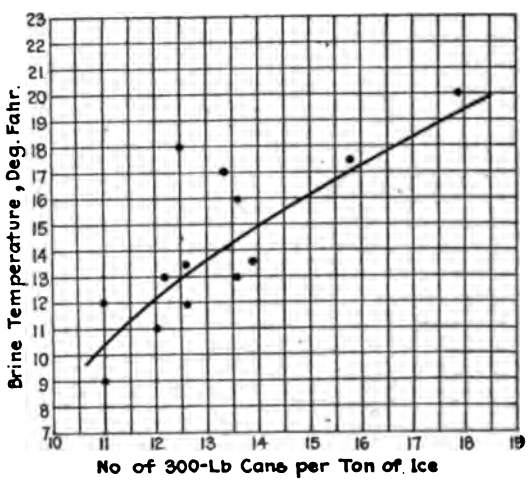


FIG. 7 FREEZING RATE OF ICE

per hr. per sq. ft., due to the insulating effect of the ice. The thicker the ice, the slower the heat exchange, consequently tank brine velocity has not nearly so great an effect upon heat transmission on the can side as it has on the coil side. The heat transmission between ammonia and brine through metal is between 10 to 20 B.t.u. per sq. ft. per hr. per deg. This comparatively low figure is primarily due to the superheating of the gas in the coil, which causes one side of the surface to be dry, and secondarily, to the low brine velocity.

46 Fig. 6 gives York Manufacturing Company curves showing heat transmission with double-pipe brine coolers and ammonia

condensers. The curves were extended by dotted lines to show probable transmission at low velocity. These curves purely from their characteristics show the importance of velocity, an item which from the economy standpoint is certainly worthy of very careful investigation.

47 Fig. 7 gives the can surface used per ton of ice in various installations and shows distinctly the low values of heat transmission obtained and also the differences found in various installations. The greater the brine velocity, the wetter the gas in the coil; the more coil and can surface per ton of ice, and the thinner the ice, the greater will be the economy of the plant. The more can surface the better, but the surface must be in effective use, not idle; that is, as soon as the ice block is frozen solid it should be pulled out.

TABLE 2 EFFECT OF FROZEN BLOCKS ON TANK EFFICIENCY

A. Ice Drawn as soon as Block is Frozen Solid	
Cans per ton ice	17—300 lb.
Pipe per ton ice	280 ft. of 1½ in.
Tank temperature	17 deg. fahr.
Back pressure	22 lb.
Hp. per ton ice, 24 hours	60.5
B. 10 per cent of Cans in Tank Containing Solid Frozen Blocks	
Cans per ton ice	15—300 lb.
Pipe per ton ice	280 ft. of 1½ in.
Tank temperature	15½ deg. fahr.
Back pressure	20.6 lb.
Hp. per ton ice, 24 hours	63
Loss B over A	4 per cent

48 Many plants operate with very low suction pressures in winter, due to the common practice of using the ice tank as an ice storage. Table 2 shows the increase of the compressor power required when the ice is not drawn promptly. These data were obtained from a plant of 100 tons of ice-making capacity per day, and they do not include incidental losses.

AMMONIA EVAPORATING SYSTEMS

49 With expansion coils in ice tanks and cold-storage rooms a high heat transmission is very desirable, and it can be obtained inside of the pipes either by flooding them or using a high gas velocity. The objection to high gas velocity in this connection is pressure drop, which for thermodynamic reasons is rather more important on the evaporating side than on the condensing side. For this

reason the length of the evaporating coil should be limited so that the velocity will never exceed the average figure of 500 ft. per min. Some tank coils are 1500 ft. long and their rather high velocity causes a great pressure drop. For long tanks 2-in. pipe is to be preferred, since the relative surface of $1\frac{1}{4}$-in. and 2-in. pipe is in the ratio of 1 to 1.5, while the sectional area is in the ratio of 1 to 2.2. Coils should be short so that they are thoroughly effective, and even flooded coils should be as short as possible.

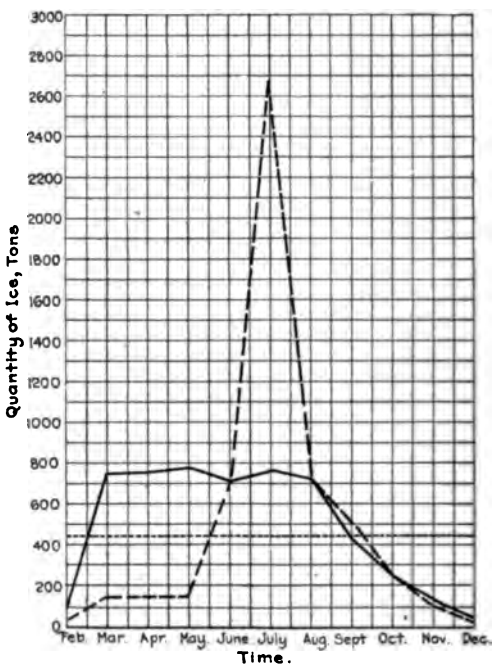


FIG. 8 EFFECT OF ICE STORAGE ON EXTREME LOAD-FACTOR VARIATIONS

50 As to the size of suction lines leading to the machines, efforts should be made to have them below 100 ft. in length and with the least number of elbows. For greater lengths the size should be governed by permissible gas velocity, friction, and radiation loss. The main considerations are the cost of fuel and the cost of installation.

ICE-PLANT LOAD FACTOR — ICE STORAGE

51 Ice storage is profitable in most cases if the storehouse is filled to capacity during the winter and emptied entirely in the

summer. The cost of storehouse will be from $6 to $12 per ton capacity and the investment will net a substantial return in most cases. The objections to it are the cost of refrigeration for the storage and the increased cost of handling the ice.

52 As far as plant economy goes, the value of ice storage is due to the equalization of the load factor. That is, the plant can be operated at higher rate during slack seasons and there may not be the necessity for forcing the plant beyond its economical limit in summer. With poorly designed and operated plants, ice storage is of far greater value, since the load factor has a greater influence upon such plants. There the economy fluctuates almost in proportion to the load factor, while in well-operated plants it is more uniform and at times fluctuates in opposition to the load curve.

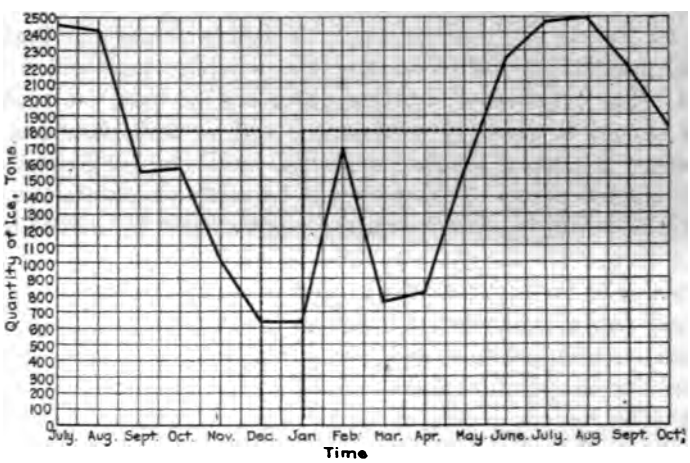


FIG 9 PROPER AND IMPROPER LOAD-FACTOR DISTRIBUTION WITH ICE STORAGE

In new installations, the ice plant and ice storage can be so proportioned that the manufacturing part of the ice plant will have a load factor of 80 to 90 per cent, while without ice storage it would be only about 40 per cent, taking the whole year into consideration.

53 The small ice vault, or daily ice storage, exerts also quite an influence upon plant economy and it cannot be over emphasized that it is advantageous to make it amply large. The idea is to remove ice from tanks as quickly as possible — to use ice tanks for storing ice is a very poor practice. In Fig. 8 the full line represents the output of ice; the broken line indicates the sale of ice, and the dotted line the proper rate of manufacturing ice. These curves

were plotted from the figures actually obtained in a plant. An exact determination of the proper rate of manufacturing ice will permit stopping the plant altogether for a certain time and attending to repairs. Fig. 9 illustrates this case. The dotted line indicates the proper rate of manufacturing ice.

54 In the majority of cases the economy of ice plants is lower in winter than in summer, whereas the economy in winter should be as good, if not better. The reason for the poorer economy is that advantage is not taken of atmospheric conditions and other favorable features which exist in the winter time.

55 To operate with low suction pressure is far less economical than is indicated by the analysis of compressor performance alone, for the reason that the economy of the engine is also affected by the reduction of load. For this reason, when the condenser pressure drops off during the cold season it is doubly important that the suction pressure be increased and the machine maintained fully loaded. The practice of shutting down one or more ice tanks in winter should be strongly condemned, and no tank should be shut off (except in case of absolute necessity) until the back pressure is at the highest point. Efforts should be made to maintain a back pressure of 30 lb. in winter, and the plant should be designed with that in view. The largest loss, even in plants otherwise well operated, is due to the fact that the various elements are not adjusted to the load factor, and that a constant relation is not maintained between suction pressure and can surface per ton, and between atmospheric temperature and condenser pressure.

56 The various rooms or tanks in an ice plant should either be maintained at the same temperature or designed especially for low temperatures. To try to maintain one or two rooms at a low temperature and sacrifice the economy of the whole plant is bad practice, since the suction pressure will always correspond to the lowest temperature. The temperatures should be maintained as uniform as possible. When this is not possible, and the difference in the various temperatures is great, then either a multiple effect or a booster compressor should be installed.

FORECOOLERS AND MULTIPLE-EFFECT RECEIVER

57 In a well-designed and efficiently operated ice plant the water to be used for ice making is cooled down to within a few degrees of the coldest circulating water, or ordinarily to a temperature of 70 or 80 deg. fahr. This water then passes into the fore-

cooler to be precooled by ammonia. The heat absorbed by the forecooler can be anywhere up to 30 per cent of the total heat to be extracted in making ice, and the water will be cooled down to about 40 deg. fahr. There are two methods of forecooler refrigeration: by feeding liquid ammonia directly into a coil, or by passing wet return gas from the tank through the water cooler. The first has the advantage that it can be connected to a machine working independently from the freezing tank and thus enable the maintenance of very high suction pressure. The only advantage of passing the suction line through the forecooler is that the expansion valves

TABLE 3 ECONOMIC EFFECT OF OPERATING COMPRESSOR INDEPENDENTLY ON FORECOOLERS WITH HIGH SUCTION PRESSURE

CASE I	ONE COMPRESSOR	
	Back Pressure:	
	Ice Tank, 15 lb	Forecoolers, 15 lb
	Relative Amount Refrig. Work:	
	Ice Tank, 70 per cent	Forecoolers, 30 per cent
	Compressor Power per Ton of Refrig.:	
	1.74	
CASE II	TWO COMPRESSORS	
	Back Pressure:	
	Ice Tank, 15 lb	Forecoolers, 35 lb
	Relative Amount Refrig. Work:	
	Main Compressor, Ice Tank 70 per cent	Auxiliary Compressor, Forecoolers 30 per cent
	Compressor Power per Ton of Refrig.:	
	Main Compressor, 1.21	Auxiliary Compressor, 0.32
	Total, 1.53	
	Saving over Case I, 12 per cent	
CASE III	ONE COMPRESSOR WITH MULTIPLE-EFFECT DEVICE	
	Back Pressure:	
	Ice Tank, 15 lb	Forecoolers, 35 lb
	Secondary Pressure in Compressor:	
	27.5 lb	
	Compressor Power per Ton of Refrig.:	
	1.1	
	Saving over Case I, 34.7 per cent	

on the tank can be kept open wider, thus insuring that the freezing coils will work throughout their whole length without danger of getting any liquid to the machine. But this same thing can be accomplished far better by means of liquid separators and it is of greater advantage to use the high suction pressure which is possible with direct feeding.

58 Refrigerating plants should also be equipped with double-pipe liquid precoolers, cooling the liquid from the temperature of the coldest circulating water down to the temperature corresponding to the highest suction pressure used. In this connection a

multiple-effect liquid receiver can also be used, by means of which a greater amount of work can be done at high suction pressure than by the use of the double-pipe cooler alone.

59 Every refrigerating plant should have an auxiliary compressor for high-pressure work. The size of this compressor may be relatively small for the reason that it will operate at double its rated capacity. Table 3 shows what economic effect such a compressor will have by operating it independently on the forecoolers with high suction pressure. In addition to a saving of power equivalent to 12 per cent, the machine capacity will be increased 15 per cent over all. There is also a decided increase in compressor capacity in Cases II and III over I, especially in Case III, where, with the same speed, there is a 50 per cent greater capacity.

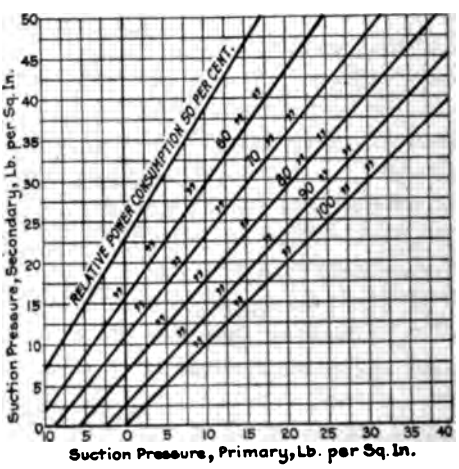


FIG. 10 INFLUENCE OF MULTIPLE EFFECT ON COMPRESSOR EFFICIENCY

60 One of the most valuable inventions ever made in the refrigerating field is the multiple-effect compressor, which allows gas of higher suction pressure to enter the cylinder after it has been filled with gas of a lower pressure. Although it must be admitted that mistakes have been made in its application, there are installations where it is an absolute success. In a certain plant having sharp freezers and ice tanks, two compressors were operated for a long time, summer and winter, one upon low pressure and the other upon high. After adopting the multiple-effect device, the work was done without the slightest complications. With some compressors on the market it is very simple to use the multiple effect;

with others, the arrangement is somewhat complicated. Table 3 shows the relative benefit derived from operating the forecoolers by means of the multiple effect.

61 Commenting further upon distilled-water coolers, which ordinarily are nothing but storage tanks with coils immersed, if the suction pressure is raised, the temperature difference will be reduced and a low temperature of the water will not be obtained unless more pipe is put in.

62 Since the circulation in such tanks is very bad, a much higher heat transmission can be obtained by circulating the water

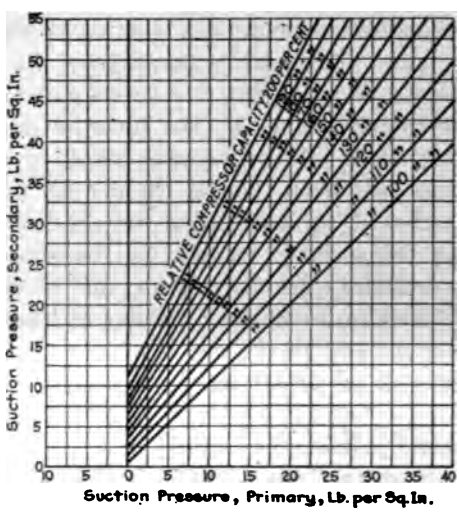


FIG. 11 INFLUENCE OF MULTIPLE EFFECT ON COMPRESSOR CAPACITY

to gain some agitation. Fig. 10 indicates the influence of the multiple-effect method upon compressor efficiency. The curves are based upon 185 lb. condenser pressure and the York Manufacturing Company's data as to compressor horsepower required. Fig. 11 indicates the influence of multiple effect upon compressor capacity.

AMMONIA CONDENSER

63 There is no reason for a condenser pressure as high as 200 lb. It always indicates improper conditions, and even in a hot climate the condenser pressure should be below 175 lb. In the hottest summer weather and when there is a relatively high wet bulb, the following results are to be expected with properly proportioned installations:

Air temperature	100 deg. fahr
Wet bulb	80 deg. fahr.
Water off cooling tower	83 deg. fahr.
Water on ammonia condenser	83 deg. fahr.
Water off ammonia condenser	88 deg. fahr.
Temperature difference, on and off	5 deg. fahr.
Condenser heat transmission	150 B.t.u.
Condenser temperature difference	7.5 deg. fahr.
Condenser surface per ton	26 sq. ft.
Condenser pressure	177 lb.

64 The cooling tower should cool the water within three degrees of the wet bulb. The relative positions of the condenser and cooling tower should be such that five to six gallons of water can be pumped economically; that is, the pressure due to the head should be less than 15 lb. The condenser should give a heat transmission of at least 150 B.t.u. per sq. ft. per hr. per deg. There should also be sufficient surface, and if the condenser gives better results, less than the specified surface will be needed. In actual practice, results ordinarily are far inferior, due to the water being too warm, to the lack of a sufficient amount of water or of the required condensing surface, to the use of a poor type of condenser, or to the presence of oil or air in the condenser or scale on the outside.

65 Atmospheric condensers should not be penned in, but placed in such a way that the wind has free access. With a fair wind, the humidity of the air passing between the condenser stands should increase only a little. In a great many plants condensers are situated in such a way that the air not only does not cool the water by evaporation, but actually gives up heat to it. Often condensers will be found with 100 per cent humidity between the stands.

66 The amount water can be cooled by evaporation when passing over the condensers depends upon the temperature of the water and the wet-bulb temperature of the air in contact with the water. The cooling effect is surprisingly large and it can be as great as 100 per cent, that is, all the heat given up by the ammonia may be lost by evaporation, and the water leaving the condenser may be at the same temperature as the water going in.

67 The condenser should be located on the roof of the building, with the cooling tower immediately underneath and so placed that

the coils will be parallel with the prevailing direction of the wind in the summer.

68 The cooling of the water while passing over the condensers is important, not only because it simplifies the action of the cooling tower, but also because it produces a greater temperature difference between the water and the ammonia and thus lowers the condenser pressure. Theoretically the ideal arrangement would be for the initial and final temperatures of the water to be the same. This is often realized in winter and is also quite possible in summer in a dry climate with good wind velocity and sufficient condenser surface.

69 It is important to protect atmospheric condensers from the sun. Failure to do so may raise the condenser pressure considerably, and if this happens, the benefit derived from the evaporation of the water will be greatly reduced or entirely destroyed. This is proven by the mere exposure of the wet-bulb thermometer to the sun.

TABLE 4 AMMONIA CONDENSER PERFORMANCE

No. of Test	1	2	3
Type of Condenser	A	B	B
Internal Surface per Stand	174 sq. ft.	222	216
Refrigeration per Stand	13.8 tons	5.7	6.5
Surface per Ton of Refrigeration	12.6 sq. ft.	39	33.2
Water on	73 deg. fahr.	93	84
Water off Last Condensing Pipe	98.5 deg. fahr.	94	90
Water off Bottom Superheat Pipe	104 deg. fahr.	94.5	92
Condenser Pressure	195 lb.	190	210
Condensing Temperature	98 deg. fahr.	97	103.4
Temperature Entering Gas	240 deg. fahr.	230	245
Temperature Leaving Liquid	98 deg. fahr.	97	100
Logarithmic Temp. Diff., Condensing Section	6.6 deg. fahr.	3.5	16.5
Logarithmic Temp. Diff., Superheat Section	24 deg. fahr.	37.5	57
Superheat Extracting Surface per Stand	21.7 sq. ft.	22.2	32
Condensing Surface per Stand	152.3 sq. ft.	199.8	184
Entering Velocity Superheat Section, Feet per Second	8.2	3.3	3.7
Entering Velocity Condensing Section, Feet per Second	6	2.4	2.7
Mean Heat Transmission in Stand per Deg. per Sq. Ft. per Hr.	155 B.t.u.	91.6	26

70 Condensing coils give a much greater heat transmission per degree difference in temperature than evaporating coils. Better results are obtained with the double-pipe condenser than with the atmospheric because of the higher water velocity of the former. Taking into account the question of initial cost, however, an atmospheric condenser, well exposed, should give, for the same expenditure, as good results as the double-pipe condenser.[1]

[1] See important article on ammonia condensers by Fred Ophuls, in *A.S.R.E. Journal*, November 1914.

71 Table 4 gives the results obtained from tests performed upon condenser sets in actual operation. Type A was a countercurrent flooded atmospheric condenser. Type B was a condenser installation consisting of ordinary atmospheric condensers with three superheat pipes at the bottom of each stand. The result in Tests 2 and 3 were obtained with type B. When Test 2 was conducted the condenser surface was very clean both inside and outside and the condenser was free from any non-condensable gases; this probably accounts for the favorable performance secured. The values in Test 3 fairly agree with the ordinary performance of condensers similar to B. The writer possesses data of tests performed upon a dozen of these installations, which show practically the same figures.

TABLE 5 PERFORMANCE OF HIGH-VELOCITY CONDENSER

Surface per Stand	130 sq. ft.
Stands in Battery	6
Refrigeration per Stand	7.7 tons
Refrigeration per Battery	46.2 tons
Surface per Ton Refrigeration	16.9 sq. ft.
Water on	84 deg. fahr.
Water off	89 deg. fahr.
Condenser Pressure, Gas Header	178 lb.
Condenser Pressure, Liquid Header	167 lb.
Mean Condensing Pressure Assumed	173 lb.
Mean Condensing Temperature	92 deg. fahr.
Temperature Entering Gas	100 deg. fahr.
Pressure Drop through Condenser	11 lb.
Temperature Difference, Mean	5.1 deg. fahr.
Entering Velocity, Condenser Section	36.6 ft./sec.
Heat Transmission, B.t.u. per Sq. Ft. per Deg. per Hr.	145

72 Not only is the transmission of heat in a condenser affected by the velocity of the water, but also to a great extent by the velocity of the gas; in fact, if the latter is increased sufficiently in a plain atmospheric condenser, as rapid a transmission of heat can be secured in it as is usually obtained in a flooded condenser.

73 The data in Table 5 show the performance of an atmospheric condenser built especially for very high gas velocity. This condenser, Fig. 12, gave good results, but it developed so many complications that it cannot be recommended as a practical type.

74 Fig. 13 presents the effect on the transmission of heat of the velocity of the water in the pipes of a condenser. The points in the graphs were plotted from values obtained with a 12-pipe condenser of the drip-pipe type.

75 The velocity of the water in the pipes of a double-pipe condenser may be increased by allowing a greater amount of water to flow through them. The gas velocity increases when the height of the stand is increased by the addition of more pipes. In selecting between high and low condensers, however, other factors must

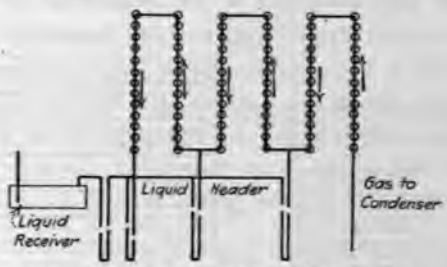


FIG. 12 HIGH-VELOCITY CONDENSER

be considered in addition to the water or gas velocity. Generally speaking, high condensers are preferable when the available water is cold.

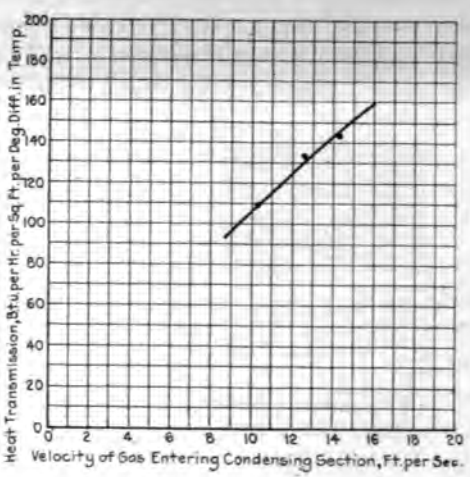


FIG. 13 EFFECT OF VELOCITY UPON HEAT TRANSMISSION

76 When a condenser is operated with superheated gas, this should not enter at the top of the stand, as is often done in practice. Type B in Fig. 14 is a convenient form of condenser for use with superheated gas.

77 The heat transmission in atmospheric condensers operated with superheated gas is often so poor that the gas passes through

as many as five pipes before it is reduced to the saturated state; such a condition never arises in a flooded condenser, in which the condensing surface is more effective.

78 A rather frequent objectionable condition is the presence of air in the condenser. In order to be able to extract it without interfering with the operation of the remainder of the system or

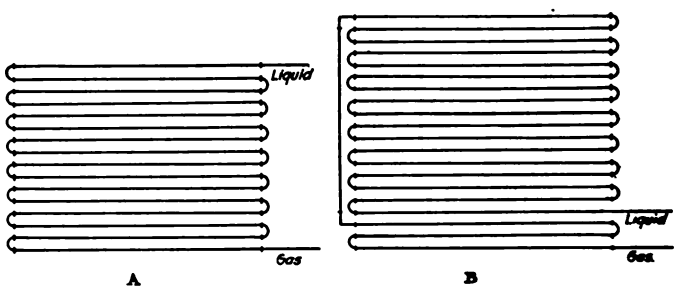


FIG. 14 AMMONIA-CONDENSER TYPES

losing much ammonia, the condenser must be provided with a suitable purging arrangement, as, for example, the one represented in Fig. 15, which was used with installation B, in Test 2, Table 4.

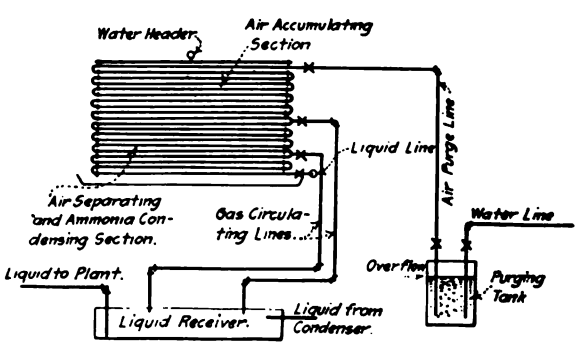


FIG. 15 NON-CONDENSABLE GAS-PURGING ARRANGEMENT

79 The presence of air in the condenser often causes the cessation of the flow of the liquid through the pipes and thus seriously impairs the efficient performance of the condenser. The author has had occasion to observe in certain plants he inspected that the condenser pressure dropped 20 to 30 lb. after the air was removed from the system.

80 To secure a proper gas circulation and distribution in the

stands it is best to have separate coils for condensing and cooling, both operating on the counter-current principle.

81 Figs. 16 to 22 illustrate various features of condenser installations under most of the usual conditions. One ton of refrigeration has been taken as requiring the removal of 350,000 B.t.u. per 24 hours by the condensing water.

COOLING TOWERS AND SPRAY SYSTEMS

82 The economy of a refrigerating plant depends largely upon the temperature of the water circulated in the condenser. Water for ammonia-condensing purposes can be obtained from deep or surface wells, flowing streams or city distribution systems; or by recirculating water that is being cooled in forced-draft, natural-

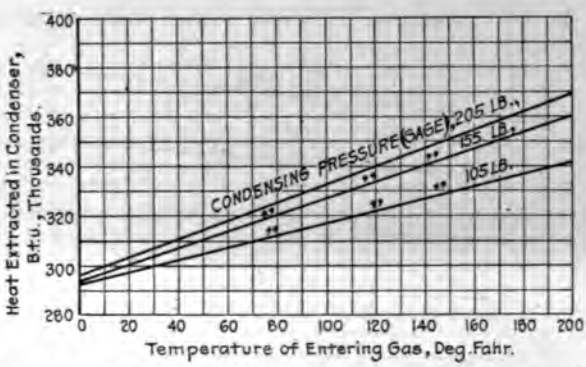


FIG. 16 HEAT TO BE EXTRACTED BY CONDENSER WITH VARIOUS DEGREES OF SUPERHEAT

draft or atmospheric cooling towers or spray cooling systems. Which method is to be preferred depends upon the temperature of the water, the dependability of the supply and the relative pumping level.

83 The cost of pumping water from wells, or even flowing streams, is ordinarily so great that a recooling system is preferred. The relative values of these various systems will now be considered.

84 The first cooling tower in this country was erected twenty-five years ago by the Ruemmeli & Dawley Manufacturing Company at the St. Louis plant of the Anheuser-Busch Brewing Association. The tower was of the forced-draft type, which was almost exclusively used at first. At the present time, however, atmospheric towers and spray cooling systems are used which give equally as good results.

85 The proper construction of a cooling tower is far more important in a refrigerating plant than in a steam plant. In the latter we can get 25 in. of vacuum with water at 105 deg. fahr.: but in the refrigerating plant, with the same temperature, the ammonia condenser pressure would be about 280 lb.

86 The limit of atmospheric cooling depends upon the wet-bulb temperature. The rate of cooling depends upon the vapor-pressure difference between the dewpoint and the temperature of the cooling water as modified by the wet-bulb depression. Roughly speaking, each degree of water temperature is equivalent to three pounds of condenser pressure.

87 A forced-draft tower is most dependable, but the objection to it is that it increases the auxiliary power. Far more air is required to cool ammonia-condenser water than steam-condenser

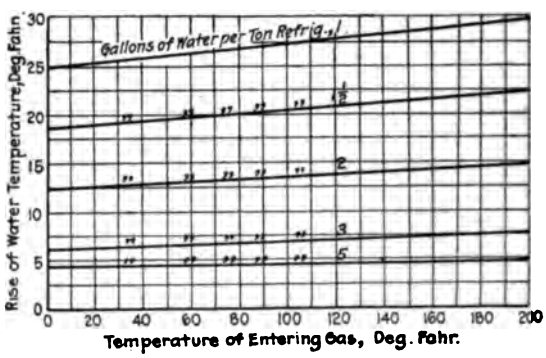


FIG. 17 EFFECT OF SUPERHEAT ON WATER-TEMPERATURE RISE

water and also a great deal larger cooling surface, since the cooling in the ammonia condenser takes place below the atmospheric temperature. Fan power is directly proportional to the volume of air blown and to the square of the resistance. A forced-draft cooling tower should be so proportioned as to give a cooling efficiency of from 80 to 90 per cent. It is desirable to maintain the auxiliary power at 0.5 hp. per ton of ice. Most towers in actual operation give a cooling efficiency of only 50 to 60 per cent. Some tested by the writer gave only 30 per cent.

88 Of all the economic factors entering into the operation of refrigerating plants, the proper distribution of the water over the cooling tower is receiving the least attention. Cooling-tower performance should not be judged alone by the approach of the final temperature of the water to that of the wet bulb, but also by the

approach of the temperature of the emerging air to that of the entering water. Failure to obtain this last requirement in any of the sections of the horizontal uppermost part of the tower indicates that there is an unequal distribution of the water on the tower

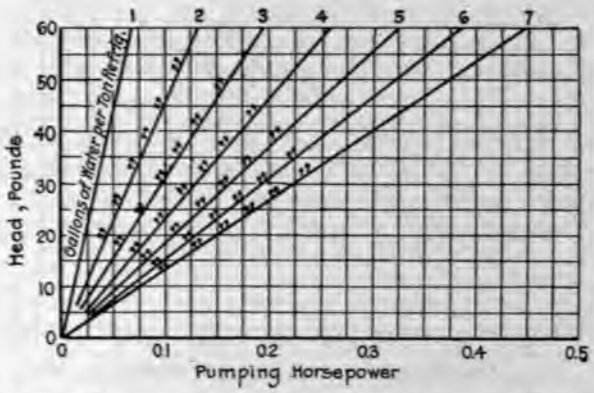


FIG. 18 PUMPING HORSEPOWER OF CIRCULATING WATER PER TON REFRIGERATION

surface, a condition which will reduce the efficiency of the cooling tower.

89 The growth of algæ in distributing troughs is chiefly responsible for poor water distribution and it is well, in such cases,

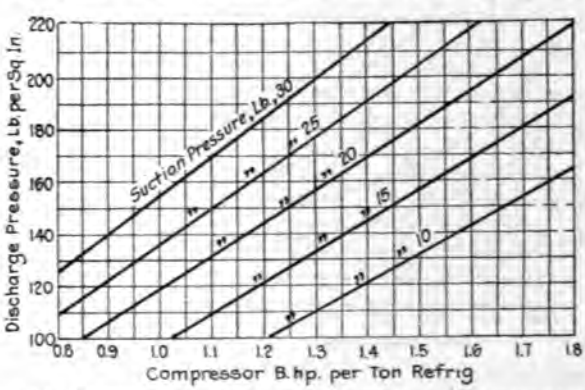


FIG. 19 COMPRESSOR HORSEPOWER PER TON REFRIGERATION

to build cooling towers with roofs so as to keep off the sun's rays and thus effectually prevent any large growth of moss. These roofs should be built sufficiently high to prevent undue air friction and should protrude from the sides of the tower to such an extent

that the sun will never strike the troughs. It is well to check the cooling-tower efficiency frequently as the troughs easily get out of level.

90 The use of a properly designed cooling tower is preferable

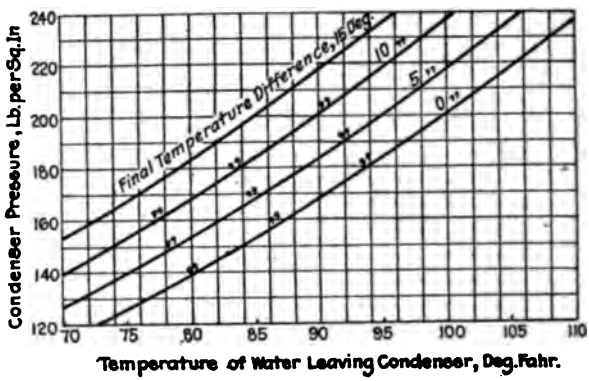


FIG. 20 CONDENSER PRESSURE WITH VARIOUS FINAL TEMPERATURE DIFFERENCES

to pumping water from a well, except when the well water is very cold. In summer, in even the hottest and most humid parts of the United States, the temperature of the water in the cooling

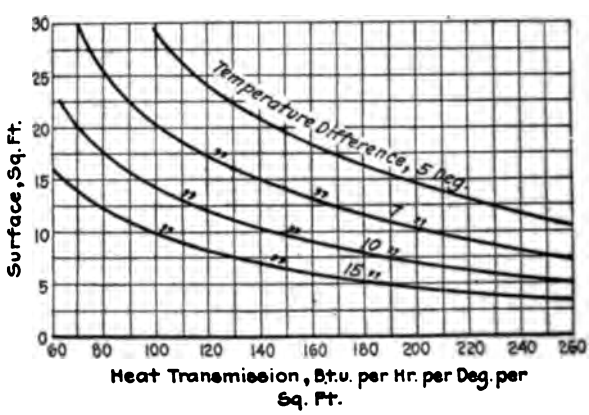


FIG. 21 CONDENSER SURFACE REQUIRED WITH VARIOUS HEAT TRANSMISSIONS AND TEMPERATURE DIFFERENCES

tower will hardly ever be 85 deg. fahr.; it will ordinarily be below 80 deg. fahr. and in winter 50 deg. fahr. and even less. In fact, with a cooling tower it is not impossible to obtain in winter a condenser pressure of 65 lb., while with well water, the temperature of

which keeps more uniform throughout the year, the pressure is higher in winter. The results obtained by the use of river water for condensing ammonia compare more favorably with those secured by the operation of a cooling tower; the temperature of the river water, however, will not greatly differ from the temperature of the water in the cooling tower, but the pumping head of the river water will be greater than that required for the operation of the cooling tower.

91 A natural-draft tower is as dependable as a forced-draft tower, though the air flow is induced in the former by the chimney effect. A natural-draft tower should not be considered for an ammonia condensing installation, but it serves well for steam condensers.

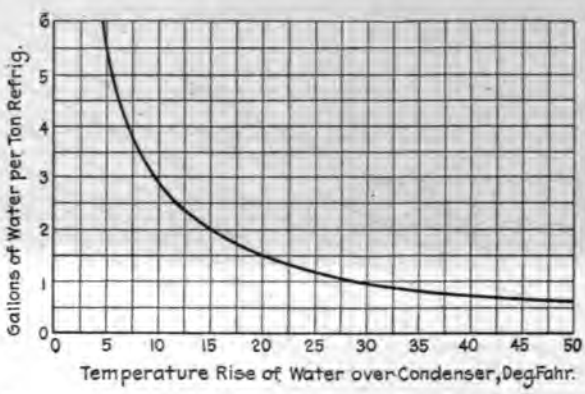


FIG. 22 TEMPERATURE RISE OF WATER OVER CONDENSER WITH VARIOUS AMOUNTS OF WATER (PER MIN.) AND NO ATMOSPHERIC COOLING

92 Atmospheric towers are quite satisfactory. They depend for their operation upon wind velocity and since this in the United States is ordinarily between eight and fourteen miles per hour, seldom below four miles, and hardly ever zero, they give very good results in even such territory as Louisiana. In that state the temperature of the water in an atmospheric tower was lowered, under favorable conditions, to within two degrees of the wet-bulb temperature and to within eight degrees under adverse conditions; the average approach was three and one-half degrees. In a drier territory still better results can be obtained.

93 Before building the cooling tower, the average atmospheric conditions of the locality, such as the predominating direction of the wind and the average wind velocity in summer, should be care-

fully determined and the tower placed with regard to the wind direction and not with regard to its symmetry with the other buildings. The towers should not be built square but rectangular, twice as long as they are wide, and should be placed so that the wind strikes on the longer side.

94 The proper relative position of the cooling tower, as regards the condenser, is a most important feature. It must be remembered that the auxiliary power should be kept down to the minimum of 0.5 hp. per ton of ice, also that if the head is reduced more water can be pumped with the same power and thus lower condenser pressures are obtained. In many plants the cooling tower and

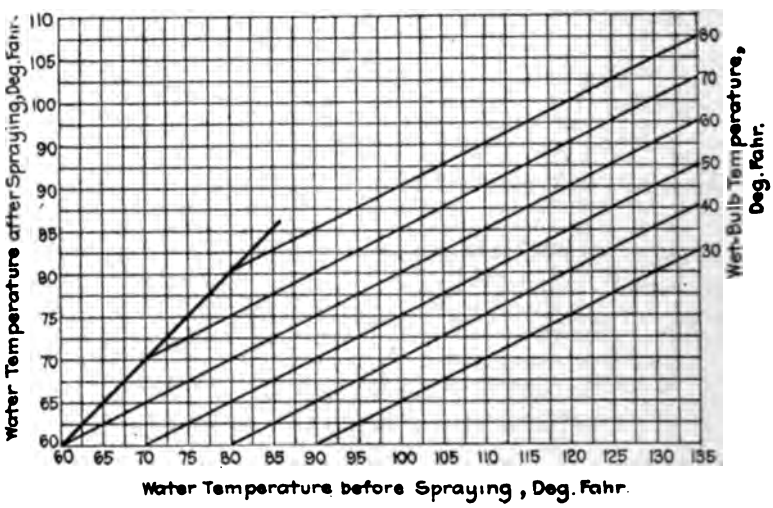


FIG. 23 PERFORMANCE OF SPRAY SYSTEM

the condenser are placed on the same level with the result that tw circulating pumps are operated in place of one. The relative po tion of the cooling tower and the condenser should always be o above the other, with the preference of the condenser being in t higher position, since unobstructed air access is more import with an atmospheric condenser than with a cooling tower. B are more conveniently located upon a roof.

95 The spray system has recently been introduced in con tion with ammonia condensing systems and very good results being obtained. Its cooling efficiency varies from 45 to 70 per depending upon humidity, wind velocity, fineness of spray pressure at the nozzles. In the calculations which must be ma

designing a spray system, however, it is advisable to figure its operating efficiency at 50 per cent. This value has been assumed in the preparation of the curves in Fig. 23, which show the value of the temperature of the water before spraying and the corresponding values after spraying, for various wet-bulb temperatures.

96 The advantage resulting from the use of a spray system in an ammonia condensing installation is that it reduces the power required, because a spray system does not involve the action of a fan, and a pressure at the nozzle of only six or seven pounds, that

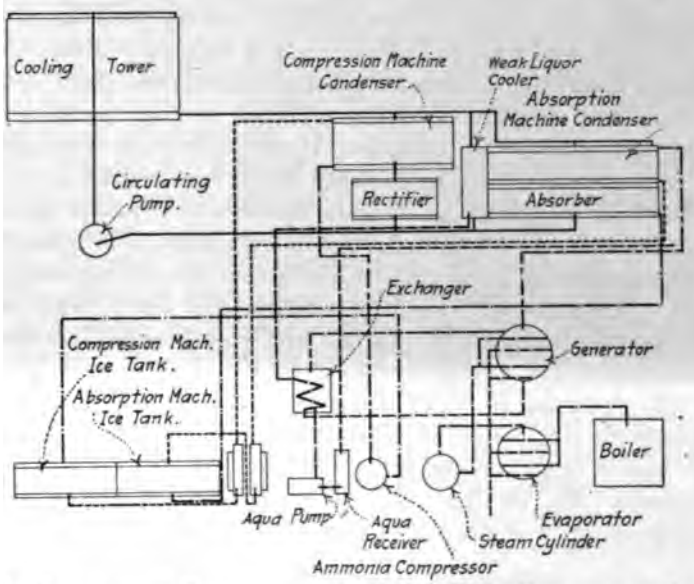


FIG 24 COMBINATION COMPRESSION, ABSORPTION AND EVAPORATION SYSTEM

is, the equivalent of a tower 14 ft. high is sufficient. Also, the cost of construction and maintenance is less for a spray system than for a cooling tower.

ABSORPTION MACHINES

97 In the absorption machine the generator or ammonia boiler acts as a steam condenser and thus the latent heat of the steam is made available.

98 The steam pressure required for the operation of the low-pressure type depends upon the temperature of the water in the ammonia condenser, the temperature of the water in the absorber

the pressure in absorber, and the dimensions of the surface and the efficiency of the absorber, the condenser and the generator.

99 With brine temperatures between 15 and 0 deg. fahr. low-pressure machines are not used, but could be made available by the employment of either a reciprocating or a centrifugal booster that would compress the gas after leaving the evaporator to, say, from minus 5 lb. to plus 15 lb.

100 The low-pressure absorption machine can be operated successfully even when the available water has a temperature of 80 deg. fahr. Considering therefore, that atmospheric conditions throughout the United States make it entirely possible to obtain water at 80 deg. fahr. in summer, it may be assumed that the low-pressure absorption machine is practical throughout this country.

101 The amount of water required in the operation of an absorption machine is variable. If the absorption machine is of the high-pressure type, on account of the gradual rise of the temperature of the water as it flows through the various apparatus, the total amount of water required is not greater than the quantity usually needed in the operation of a steam condensing compression plant. A low-pressure machine, on the other hand, often requires two separate streams of water, which materially increases the consumption.

102 A saving in water is effected by operating the absorption machine in connection with a compression machine, because, in this case it is not necessary to circulate other water in the steam condenser. Fig. 24 illustrates a method of combining compression, absorption and evaporation in the same system.

DISTILLED- AND RAW-WATER SYSTEMS

103 The advisability of using water evaporators should be carefully considered before adopting a raw-water system in a steam plant. Where the quantity of the available water is such tha raw-water ice cannot be made successfully, the installation of evapc rators is highly desirable.

104 There are two types of evaporators, high-pressure ar vacuum. Under proper conditions both give satisfactory servi and neither one develops as much trouble from the formation scale as is ordinarily assumed. The writer knows of evaporat operated successfully in a region where the water contains a la amount of salt, a large amount of carbonates, and consider calcium and magnesium sulphate. Of course they will hav

be cleaned and blown off the same as a boiler, but their use contributes to securing a high economy and simplifies the operation of the plant.

105 It may be added that a plant short of distilled water is wasteful, as also is the plant that wastes distilled water. A simple steam-driven ice plant should have just enough distilled water to make the ice.

LACK OF AMMONIA IN SYSTEM — AMMONIA CONSERVATION

106 A serious loss comes from operating a plant with an insufficient amount of ammonia. On account of the present shortage and Government control of ammonia, situations are found where the supply of a plant is made to last longer by not introducing enough liquid in the system.

107 The effect of this false economy is to reduce the ice-making capacity and increase the fuel consumption of the plant. Seven out of ten plants are being operated in such a fashion.

108 Shortage and conservation of ammonia are a national question now, but conservation does not mean to deplete the system, but rather to practice extreme economy. The practice of this economy, in spite of the publicity and agitation promoted by the Government, leaves still much to be desired.

109 The chief sources of ammonia loss are blow-outs, careless purging, and leaky stuffing boxes. The first can be prevented by testing the system and keeping up with repairs continuously. Condensers, ice tanks and coils should be frequently inspected, repaired when found deficient, and tested with air of not much above atmospheric temperature. Leaks develop in the stuffing boxes through carelessness in packing them or from the bending of the rod. The only remedy is strict supervision, education of the workmen and the granting of bonuses.

BONUSES

110 Ice-plant bonus systems can be of any of the following kinds:

Economy bonuses
Ammonia-consumption bonuses
Quality-of-ice bonuses
Quantity-of-ice bonuses
Service bonuses

111 The economy and ammonia-consumption bonuses are the most important, but they are defined with difficulty. In regard to economy bonuses, the best system of granting them is devised by taking the quantity of fuel used per tons of ice made in one season as an expected minimum at which no bonuses will be given, and then making a very thorough examination of the plant for the purpose of ascertaining the possibilities of increasing the output. For instance, in an ice plant making 15,000 tons of ice per year at the rate of 1.5 tons of ice per barrel of oil, a thorough examination proved that with a slight reconstruction and improved operation, 2.3 tons of ice per barrel of oil could be expected; accordingly, Table 6 was drawn up, giving the value of the savings made and

TABLE 6 BONUS OUTLINE

Tons of Ice per Bbl. of Oil	Saving, Per Cent	Cost of Fuel per Ton Ice, Dollars	Total Saving, Dollars	Bonus, Dollars	Clear Saving, Dollars	Tons of Ice per Ton of 10,000 B.t.u. Fuel
1.5	.....	0.533	.....	.....	.....	4.8
1.6	6.2	0.50	495.00	99.00	396.00	5.16
1.7	10.9	0.475	870.00	174.00	696.00	5.49
1.8	16.7	0.444	1335.00	267.00	1068.00	5.81
1.9	21.0	0.421	1680.00	336.00	1344.00	6.13
2.0	24 9	0.40	1995.00	399.00	1596.00	6.46
2.1	28.5	0.381	2280.00	456.00	1824.00	6.78
2.2	31.2	0.363	2550.00	570.00	2040.00	7.10
2.3	34.7	0.348	2775.00	555.00	2220.00	7.42
2.4	37.5	0.333	3000 00	600.00	2400.00	7.75
2.5	40.0	0.32	3195.00	639.00	2556.00	8 07

the bonus, which was taken as 20 per cent of the saving effected. The monetary value of the saving was based upon the cost of oil, in this case 80 cents per barrel.

112 The percentage of saving to be paid out as economy bonus will depend upon the size of the plant, the facility of making the saving, the magnitude of saving possible and the cost of fuel, but will range from 50 per cent in small plants to 10 per cent in large plants, or in plants where large savings are possible. Every plant should have an economy standard and the aim should be to do better every year.

113 The bonus outline should be simple so the men can understand it, otherwise their interest will be greatly reduced. The bonus should be preferably paid at the end of the season, although this depends upon conditions, and any man leaving the company during

the season without a good reason, or any man discharged through fault of his own, should forfeit the bonus.

114 The ammonia bonus should not be based only upon the amount of ammonia purchased, but rather upon the amount of ammonia in the system at the beginning of the season and the amount introduced during the season. At the beginning of the season with the whole plant working and with a known suction and discharge pressure, the amount in the receiver above the seal should be noted, and at the end of the season, the same conditions obtaining, the amount put in the system during the season should be taken as the actual consumption.

115 Quantity bonuses are usually granted when the plant is operating above its rated capacity.

116 Quality bonuses are based on the number of good blocks of ice made, with a deduction equal to two blocks for every poor block turned out.

117 The service bonus consists of a certain sum which is given to the faithful employees at the end of the season. It can be based upon the earnings of the plant and be thus converted into a profit-sharing bonus; this becomes every day more advisable with the present labor situation and the high cost of operation.

DISCUSSION

Fred Ophuls, who opened the discussion, stated that during the last few years two-stage compression had been used in refrigerating plants where it was desired to cool brine down to 10 or 20 deg. below zero (fahr.). With the higher brine temperatures, 10 to 20 deg. above zero, as used in ice-making plants, the advantage of compound compressors was not so great, particularly where well water at around 52 deg. fahr. was obtainable, and it was still a question whether in this case the increased friction of the two-stage machine did not eliminate the saving derived from compounding. There was, of course, an opportunity in ice making to cool down the water at a high and favorable intermediate ammonia evaporating pressure, such as 40 lb. gage, but this would not exceed 20 per cent of the total work and should be done in more efficient water coolers than those used heretofore.

Edward N. Trump, referring to Par. 20, said that in the uniflow engine the steam traveled only in one direction, the wall and

head temperature was much higher where the steam entered and the exhaust ports much colder than in the counterflow engine, and therefore the cylinder condensation was almost eliminated. The clearance surfaces were kept dry, reducing the heat transfer. A 150-hp. non-condensing engine required only 18 lb. of steam per i.hp-hr., and a condensing engine 11 lb., if the steam was supplied at 125 lb. pressure. Its consumption curve was also very much flatter than that of a Corliss engine, and the surface within the cylinder was kept very small. At light loads the economy of the uniflow engine was therefore nearly as high as at full load. Again, it made very little difference in the total heat consumption whether the steam was highly superheated or dry saturated.

TABLE 7 STEAM CONSUMPTION OF UNIFLOW ENGINES AT VARIOUS LOADS IN LB. PER I.HP-HR.

(Steam pressure, 150 lb. per sq. in.)

Engines Tested	¼ load	½ load	¾ load	⅝ load	1¼ load
60 i.hp., non-condensing, atmospheric exhaust	22.2	20.7	20.7	21.3	22.5
800 i.hp., non-condensing, atmospheric exhaust	20.7	19	19	19.7	20.8
60 i.hp., condensing, 26-in. vacuum	15.5	14.6	14.6	15.3	16.5
800 i.hp., condensing, 26-in. vacuum	14.7	13.8	13.8	14.5	15.8

Arthur J. Wood called attention to the effect of superheat on the steam consumption of different types of engines and noted the difference between economies from best test results and from actual guarantees. Table 7 gives values guaranteed by one of the prominent makers of uniflow engines. The figures are in pounds per i.hp-hr. for dry saturated steam and are for small and for large units built by the company. The full load of the engine is based on approximately 20 per cent cut-off non-condensing and 15 per cent cut-off condensing.

Table 7 is for dry saturated steam. With the use of superheated steam these figures, both condensing and non-condensing, would be lowered about as follows:

Superheat, deg.	50	75	100	150	200
Reduction of steam consumption, lb. per i.hp. per hour	1¾	2¼	2½	3	3¼

Note that the reduction in steam consumption is the greatest for the first 50 deg. of superheat, which is 1¾ lb. per hour, whereas the

50 deg. superheat above 150 deg. only reduces the steam consumption ¼ lb. per i.hp. per hr. In the majority of plants the superheat is seldom carried above 100 deg., this very often being due to the fact that the superheater is installed in connection with the boiler and the high superheat of 150 to 200 deg. is not obtained unless the engine is carrying a full load or an overload, which makes it necessary to crowd the fire in the boiler furnace, and such conditions are (if at all) only for short periods.

From the foregoing it appears that the percentage of reduction of steam economy for low superheat is approximately the same as the percentage of increase in volume of superheated steam over that of saturated steam. This follows the thermodynamic principles as applied to the uniflow engine, since initial condensation is so much reduced and an increase in volume due to superheat should represent a corresponding decrease in steam consumption.

A comparison of the figures here given with economies for the Corliss engine would seem to confirm the statement (also brought out by Fig. 2 in the author's paper) that under the same pressure range the uniflow engine with superheat, non-condensing, gives about the same economy as the compound Corliss, without superheat, condensing. The above gives some notion of the increasing importance of the uniflow engine, especially for plants where the load varies through a wide range from 25 to 125 per cent of the rated capacity.

Earle Ormsby said that 90 per cent of the sources of ammonia loss enumerated in Par. 109 could be eliminated by an alert and capable engineer. To make a system of granting bonuses effective as a stimulus, however, he believed that it was necessary to find some method of inventorying the ammonia in the system at frequent intervals. Waiting until the end of the season to do this made it too late to have the proper effect on the engineer.

Halbert P. Hill[1] spoke in favor of the electrically operated ice plant driven by a synchronous motor direct-connected to the ammonia compressor. The design of a synchronous motor makes it possible to build this type of apparatus for exceptionally low speeds within the range of ammonia compressors and there are many advantages in using this type of motor. The space required (width) is less than for any other type of motor and the efficiency consid-

[1] Consulting Engineer, 112 W. 42d St., New York, N. Y.

erably higher. When compared with induction or slip-ring motors of the same speed there is a decided advantage from the standpoint of price, in favor of the synchronous motor.

The fact that such a motor is operated at unity power factor and can be operated at a leading power factor makes it a desirable form of load from the central-station standpoint. The ease in starting and reliability in operation make this type of motor an ideal prime mover in the ice-making or cold-storage plant.

GEORGE A. HORNE favored electric drive because it was mutually advantageous to both the user and the central station. The central stations had to maintain large equipments to take care of peak loads during the winter. Ice and refrigerating plants required most of their power in summer. For a number of years the central stations in large cities had offered to such plants "off-peak" contracts at attractive rates. This off-peak period might extend over two to four months in winter, during which time the customer agreed to use from 4 to 8 p.m. not to exceed 20 per cent of the preceding maximum demand. Any current used in excess of this must be paid for at a high rate, but with judicious management this penalty did not arise. In fact, it was found in two 500-ton plants that the shutting down of the main compressors for four hours was hardly noticeable in well-insulated cold-storage rooms filled with chilled goods, and even in a pipe-line system there was so much reserve capacity stored up that the heat influx during such idle time could be easily removed when the machines were started at 8 p.m. In other words, an interruption of four hours out of twenty-four proved to be entirely practical, so long as the auxiliaries were kept going, and thus large ice and refrigerating plants were in position to secure a rate as low as 0.9 cent per kw-hr.

JOHN H. DILLON, commenting on Par. 34, wrote that his experience had been that where the air lift had not given satisfaction, it had been due either to improper design of the piping — which seriously reduced the efficiency — or to failure of the wells to deliver the expected quantity of water. All unnecessary valves, elbows and bends should be avoided.

No. 1660

THE CONSERVATION OF HEAT LOSSES FROM PIPES AND BOILERS

By Glen D. Bagley, Pittsburgh, Pa.
Associate-Member of the Society

Every means of accomplishing a saving in the consumption of coal is of great present importance. One of the most important means is the use of the proper heat insulation for steam pipes and boilers as well as all other heated surfaces.

This paper presents the results of a series of experiments made at the Mellon Institute of Industrial Research on 85 per cent magnesia coverings. The methods of measurement of the losses from bare and covered pipes are described and a general method for the calculation of the losses from covered surfaces is developed. The effect of the various factors of steam temperature, cost of coal, and size of pipe on the economic side of the problem is worked out and tables are given showing the proper thickness of covering to use under all conditions. The effects of air currents on heat losses have been studied and tests have also been made to determine the permanence of the original heat-insulating qualities in service. Several large-scale experiments have been made on practical installations to check up the results of the laboratory experiments under actual conditions. Tables showing the saving in coal or money which is accomplished by the use of coverings are presented.

THE purpose of this paper is to present a more complete and detailed method of solving the problems involved in the calculation of the heat losses from bare and covered pipes and the economic problems encountered in the practical application of coverings. The factors in the economic calculations are: the cost of the heat, the cost of the covering, the size of the pipe, the temperature of the pipe, and the temperature of the atmosphere. It is necessary to consider all these factors together in order to obtain a correct result.

2 The data contained in the paper are a part of the results obtained in an investigation conducted for the Magnesia Association of America by the Mellon Institute of Industrial Research. The assistance received from the Association and from the Administrative Staff of the Institute has materially aided in the successful progress of the investigation, and credit is also due to Mr. G. F. Gray, who was originally in charge of the work, and to Mr. R. H. Heilman, who has assisted in securing the data.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

3 It is generally recognized that the losses from bare pipes and boilers are considerable, but the real magnitude of these losses is little appreciated. The fact that the loss from 1000 sq. ft. of exposed surface at 100 lb. per sq. in. steam pressure amounts to over 300 tons of coal annually is sufficient justification for serious consideration of the subject.

HEAT LOSSES FROM BARE SURFACES

4 In a study of the conservation of losses, the first important fact to be considered is the actual value of the losses from bare sur-

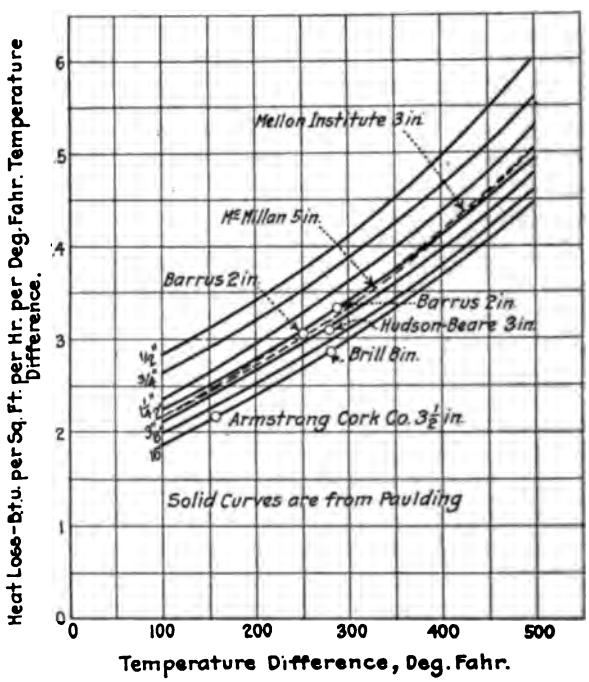


FIG. 1 HEAT LOSS FROM BARE PIPE

faces. It is often considered that the loss from any bare surface is 3 B.t.u. per sq. ft. per hr. per deg. fahr. temperature difference between the surface and the surrounding air. While this value is correct for some special cases, it is by no means generally so. Most investigators have confined their measurements to one size of pipe at one temperature difference. Both the size of pipe and the temperature difference have an important effect on the value of this constant. Paulding in his book on Steam in Covered and Bare

Pipes has worked out the theory of heat losses from bare pipes from the researches of the French physicist Péclet. The curves of Fig. 1 show the application of this theory to horizontal pipes. The solid curves indicate Paulding's values, while the dotted curves and the points give the results of various experimental tests. The curve made at the Mellon Institute on 3-in. pipe coincides at the lower end with Paulding's curve for 3-in. pipe but rises somewhat more steeply. McMillan's curve on 5-in. pipe coincides at both ends with the Mellon Institute curve but is somewhat lower throughout its length.

5 The single points made by other investigators coincide closely with Paulding's curves. It seems that Paulding's curves give the best average values for use in calculating heat losses. They show that the constant may vary from 50 per cent below 3 B.t.u. per sq.

FIG. 2 APPARATUS FOR DETERMINING HEAT LOSS FROM INSULATED PIPES

ft. per hr. per deg. fahr. to values far above it. At 500 deg. temperature difference, which is often attained with superheated steam, the constant increases to double this value for the smallest size of pipe. In some chemical plants steam is used at temperatures of 1100 deg. fahr. The importance of using very thick insulation at these temperatures is easily judged from the rate at which the loss is increasing at 500 deg. fahr. It is to be noted that these values are all considerably higher than the values given in Kent for losses from bare surfaces.

HEAT LOSS FROM INSULATED PIPES

6 The next important point in a consideration of the conservation of heat losses is the value of the loss after the pipes are insulated. The apparatus used in determining these values is shown in Figs. 2, 3 and 4. Fig. 2 is from a photograph of the apparatus as installed at

the Mellon Institute. Fig. 3 shows a cross-section of the heater with the covering applied and Fig. 4 the wiring diagram. The case of the heater, Fig. 2, consisted of three pieces of 3-in. pipe, the middle section being 3 ft. long and each end section 1½ ft. long. The sections were connected by heat-insulating disks of asbestos board and each end section was provided with a hemispherical cap of cast iron.

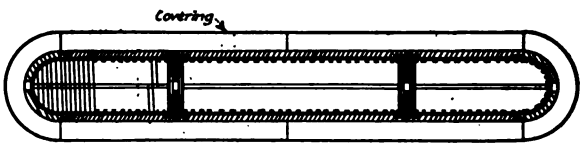


FIG. 3 CROSS-SECTION OF HEATER WITH COVERING APPLIED

Inside of each section was an electric heater made by winding resistance wire on a frame of asbestos boards. The wires were finely spaced and close to the inner surface of the pipe.

7 Tests were made on five different makes of magnesia, in 1-in., 2-in., and 3-in. thicknesses. The results of these tests are shown in

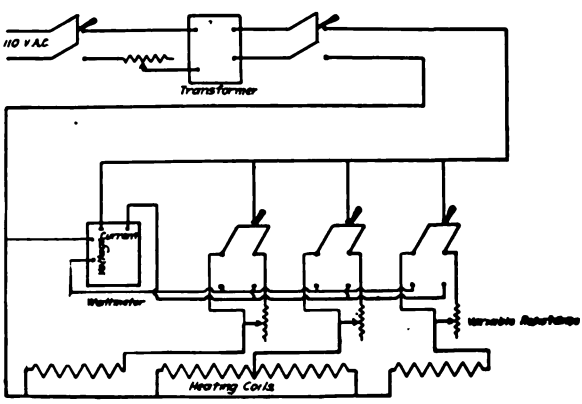


FIG. 4 WIRING DIAGRAM OF APPARATUS SHOWN IN FIG. 2

Fig. 5. These curves are all corrected for slight variations in thickness so that they are the true curves for the thickness given. Fig. 6 gives a comparison of the losses from a bare pipe with the losses through coverings 1 in., 2 in. and 3 in. thick. The contrast is very striking. The efficiency increases with the temperature as the loss from bare pipe increases much more rapidly in proportion than the loss from covered pipe.

METHOD OF CONDUCTING TESTS

8 Two standard 3-ft. sections of pipe covering were applied as shown and the ends covered with plastic. This placed half of each

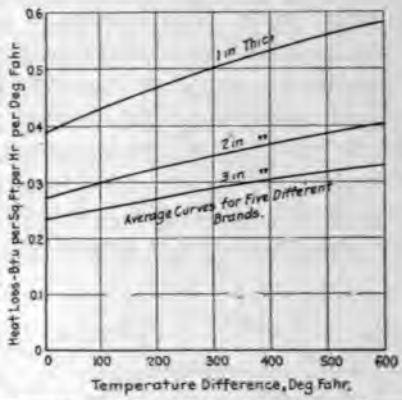


FIG. 5 HEAT LOSS THROUGH 85 PER CENT MAGNESIA COVERINGS ON 3-IN. PIPE

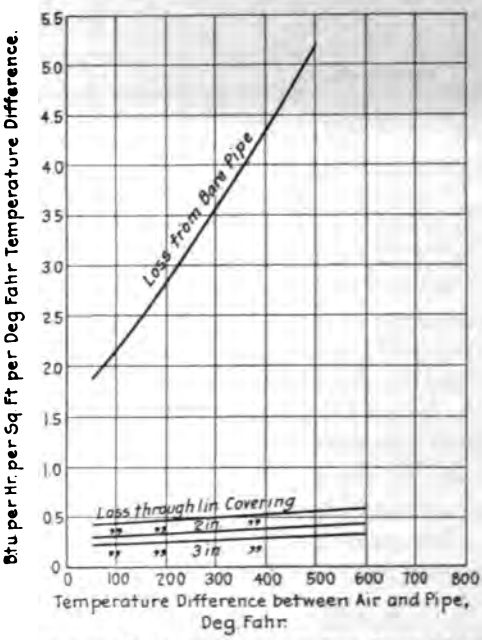


FIG. 6 HEAT LOSSES FROM 3-IN. PIPE WITH 85 PER CENT MAGNESIA COVERING

section and a joint over the middle section of the heater, a condition exactly similar to actual practice. The currents in the different

heaters were then adjusted until the temperatures shown by the thermocouples attached to the surface of the pipe were alike on both middle and end sections. The coverings were dried out for several days until conditions became constant, as shown by the readings which were taken every hour. The average of three consecutive constant readings was then used to calculate the conductivity. The power input was read on an accurate wattmeter and the temperature of the pipe by copper-constantan thermocouples peened into the surface. Since the end sections of the pipe were adjusted to the same temperature as the middle, there could be no flow of heat in a direction parallel to the axis of the pipe. This obviated the necessity for any kind of end corrections in connection with the conduc-

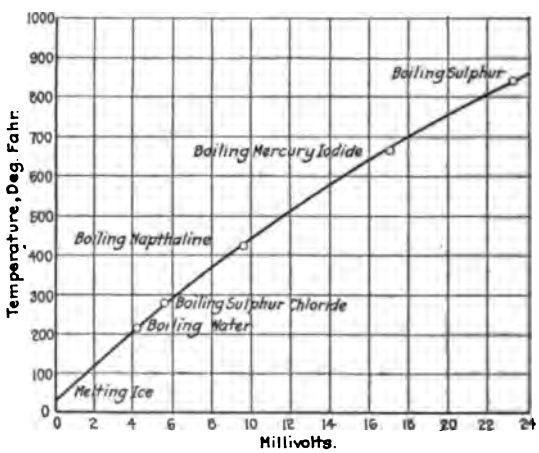


FIG. 7 CALIBRATION CURVE, COPPER-CONSTANTAN THERMOCOUPLES

tivity measurements. To obtain the conductivity of any covering in B.t.u. per sq. ft. per hr. per deg. fahr., it was only necessary to convert the power input to the middle section in kilowatt-hours to B.t.u. per hr. and divide by the area of the surface of the middle section in square feet and by the temperature difference between the air and pipe. The temperature of the air was measured by thermometers suspended several feet from the pipe.

CALIBRATION OF THE THERMOCOUPLES

9 The temperature of the pipe was measured by copper-constantan thermocouples. It was found that the variation of individual samples from the standard curve of the American Chemical

iety was so great that it was desirable to calibrate the thermo-
ples before use. This was done by the boiling-point method,
ich proved very satisfactory. The curve obtained is shown in
. 7. The apparatus used consisted of a glass tube about 2 in. in
meter and 14 in. long. About 2 in. at the bottom of the tube
filled with the liquid to be boiled. The sides of the tube were
ered with asbestos paper to protect the couple from radiation.
couple was suspended with the junction about 4 in. above the
face of the liquid, using a small glass tube for protection. The
uid was boiled just hard enough to fill the outer tube with vapor.
junction was thus 8 in. below the surface of the vapor, which
ample to prevent errors due to conduction of heat along the

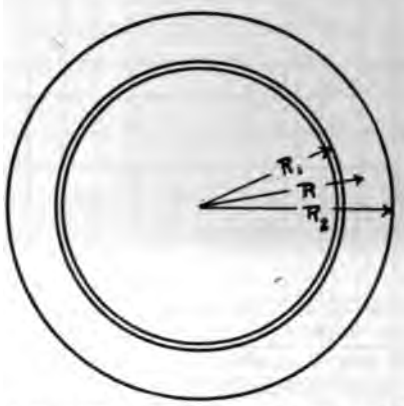


FIG. 8 DESIGNATION OF RADII FOR PIPE AND COVERING

es of the couple or the protecting tube. The cold junction of
couples was held at 32 deg. fahr. by immersion in a mixture of
and water in a thermos bottle. With this type of boiling-point
aratus the reading of the thermocouple will stay absolutely
stant for an indefinite time after the couple has been brought up
temperature, which makes the accurate determination of the
ling point possible. This method was found to be much more
sfactory than the melting-point method. A Siemens and Halske
pension-type millivoltmeter with a resistance of 889 ohms was
d in connection with the thermocouples to measure the tempera-
es. This apparatus proved very satisfactory and made it pos-
e to take a large number of readings quickly and accurately.

CALCULATION OF HEAT LOSSES THROUGH COVERINGS

10 The theoretical calculation of losses through coverings on flat surfaces is quite simple, but the problem of curved surfaces is much more difficult. In this case the effect of the increased cross-section and surface area must be taken into account. Fig. 8 shows a cross-section of a pipe and covering.

11 Since the conductance is directly proportional to the cross-

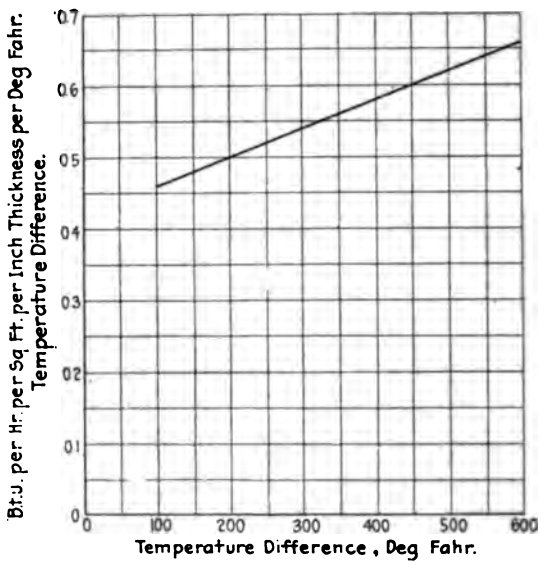


FIG. 9 ABSOLUTE CONDUCTIVITY OF MAGNESIA PLOTTED AGAINST TEMPERATURE DIFFERENCE AT SURFACES OF INSULATION

sectional area and inversely proportional to the length of the path, the increment of heat loss:

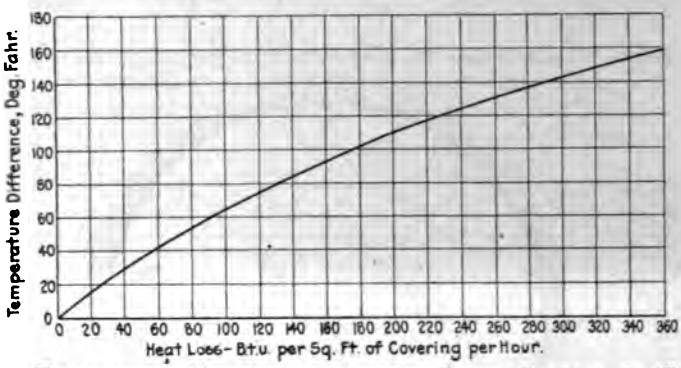
$$dH = \frac{K\,dA\,dT}{dL} = \frac{K\,(R\,d\theta\,dX)\,dT}{dR} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [1]$$

$$H = \int_{R_1}^{R_2}\int_0^{2\pi}\int_0^1\int_{T_2}^{T_1} \frac{K\,(R\,d\theta\,dX)\,dT}{dR} = \frac{2\pi K\,(T_1 - T_2)}{\log_e R_2 - \log_e R_1}$$

$$= \frac{2\pi K\,(T_1 - T_2)}{\log_e \dfrac{R_2}{R_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

where H = heat loss in B.t.u. per hr. per ft. length of covering
T_1 = temperature of surface of pipe in deg. fahr.

T_2 = temperature of surface of insulation in deg. fahr.
R = distance from center of pipe in in.
R_1 = radius of pipe in in.
R_2 = outer radius of insulation in in.
X = axial length of covering in ft.
θ = angle about center of pipe in radians
K = conductivity of the insulating material in B.t.u. per sq. ft. of cross-section per in. thickness per deg. fahr. temperature difference per hr.
dL = length of an element of the insulating material in a direction parallel to the heat flow in in. $dL = dR$ for pipe covering



:G. 10 TEMPERATURE DIFFERENCE BETWEEN INNER SURFACE OF CANVAS COVERING AND ROOM FOR DIFFERENT HEAT LOSSES

dA = cross-sectional area of the element in a direction perpendicular to the heat flow in sq. ft. $dA = R\,d\theta\,dX$ for pipe covering.

12 The loss through any pipe covering can be worked out by ıe use of this equation providing the value of K is known. K ıries with the temperature and must be obtained from an experiental curve giving the value at different temperature differences ›ove room temperature. The curve for K which was obtained ıring this research is given in Fig. 9. It should be emphasized ıat this kind of curve is the only fair basis for comparison of the eat-insulating value of the different kinds of coverings as all variaıles due to small differences in thickness, to different sizes of pipes ı which tests were made and to different surface or room condiıns, are eliminated. These curves take into account only the nduction through the material as they are based on temperature

measurements at the inner and outer surfaces of the insulating material and not on the temperature at the outer surface of the canvas covering or in the air.

13 The difference in temperature between the outer surface of the insulating material and the temperature of the ambient air is a definite function of the heat transmitted per sq. ft. of the outer surface of the covering and of the kind of protective material used

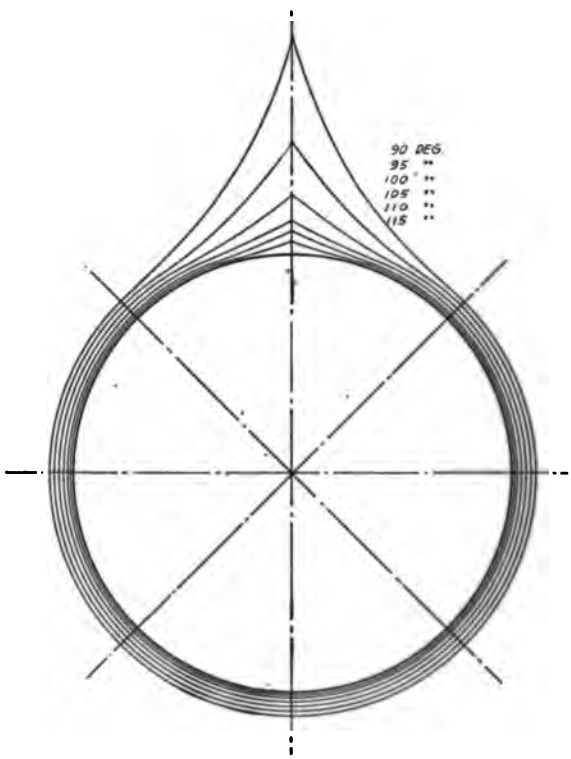


FIG. 11 EQUITEMPERATURE LINES AROUND A HORIZONTAL COVERED STEAM PIPE. TEMPERATURE UNDER JACKET, 138 DEG. AIR TEMPERATURE, 82 DEG.

over the insulation. In Fig. 10 is given a curve showing this relation for the canvas covering as ordinarily used for this purpose. This curve was developed by L. B. McMillan at the University of Wisconsin and has been checked during this investigation. To use Formula [2] for a pipe covering in still air, an estimate of the heat loss per sq. ft. of the outer surface of the canvas covering must first be made. From the curve of Fig. 10 an estimate of the temperature

eneath the canvas can then be made. Knowing this temperature nd the temperature of the pipe, the term $(T_1 - T_2)$ of the formula determined and the loss calculated. If this checks fairly well ith the estimate of the loss from the outer surface, the calculation an be considered to give the proper value for the heat lost. If not, e estimated loss from the outer surface must be changed according the indication of the calculation and the calculations repeated ntil the estimated and calculated losses check. This cumbersome rocess is necessary because of the complicated nature of the flow heat through the compound insulation composed of the insulating aterial itself and the protective covering and the effect which the rface finish has on the radiation of heat from the outer surface of e covering.

TABLE 1 EQUIVALENT THICKNESS ON A FLAT SURFACE OF VARIOUS-THICKNESS COVERINGS ON DIFFERENT-SIZED PIPES

Pipe Size, In.	Thickness of Covering, In.				
	1	2	3	4	5
¾	0.560	0.823	0.897	1.130	1.210
1½	0.679	1.073	1.350	1.570	1.740
3	0.790	1.332	1.750	2.080	2.360
6	0.878	1.565	2.135	2.620	3.040
12	0.925	1.740	2.460	3.080	3.680
24	0.960	1.843	2.680	3.400	4.150

14 In case it is desired to compute the loss per sq. ft. of pipe rface instead of per lineal ft. of covering, the limit of integration r θ must be changed from 2π to $\frac{1}{R_1}$ and the formula becomes

$$H = \frac{K(T_1 - T_2)}{R_1 \log_e \frac{R_2}{R_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

15 Table 1 gives the value of the term $R_1 \log_e \frac{R_2}{R_1}$. The physical eaning of the figures in this table is the equivalent thickness on a at surface of the given thickness on the given size of pipe. For ample, a 3-in.-thick covering on a 3-in. pipe is equivalent to a vering 1.75 in. thick on a flat surface. This table will be found great assistance in the use of Formula [3].

TEMPERATURE DETERMINATIONS IN AIR SURROUNDING A COVERED PIPE

16 In connection with this work, an investigation was made to determine the distribution of temperature about a covering in still air. Fig. 11 shows the results obtained. The lines about the cov-

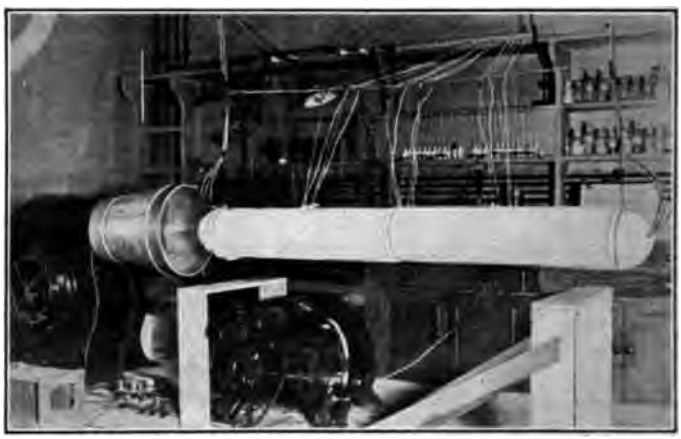


FIG. 12 ARRANGEMENT OF APPARATUS FOR TESTS IN AIR CURRENTS

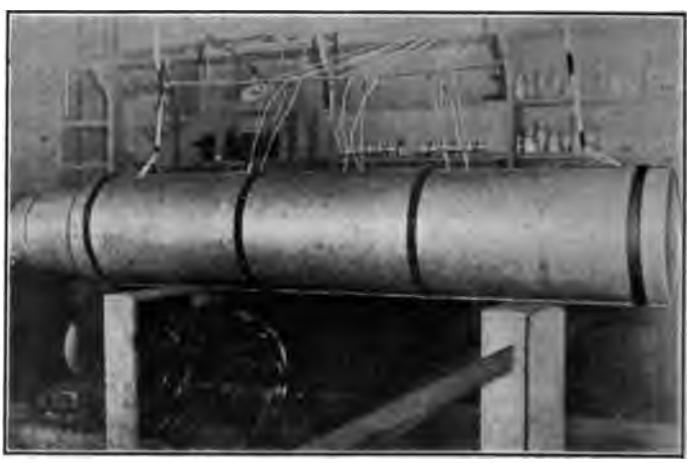


FIG. 13 WIND TUNNEL ASSEMBLED AROUND TEST PIPE

ering are equitemperature lines and are nearly parallel to the surface of the covering except at the top, which shows that no considerable error is made by assuming equal temperature distribution at the surface of the insulation in making the calculations.

EFFECT OF AIR CURRENTS ON HEAT LOSSES

17 Some tests have been made and others are now in progress to determine the effect of wind velocity on the losses from bare and covered pipes. The apparatus used to determine this effect consisted of a 35-in. Sturtevant blower driven by an 8-hp. direct-current motor which furnished a blast of air for a wind tunnel. The apparatus used for testing pipe coverings was arranged inside of the tunnel so that the axis of the pipe coincided with the axis of the tunnel. This caused the air to travel parallel to the axis of the pipe

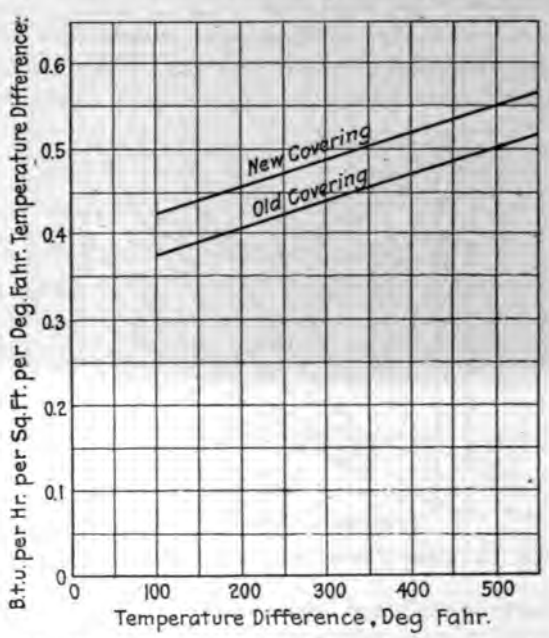


FIG. 14 COMPARISON BETWEEN OLD AND NEW COVERINGS

and gave a condition similar to that encountered in locomotive practice. Fig. 12 shows the blower and motor with the testing apparatus in place in front of the blower. Fig. 13 shows the wind tunnel assembled around the test pipe, with the thermocouple and heating wires brought out through openings. The wind velocity in the space between the tunnel and the outside of the covering was measured by an anemometer, and the distribution of velocity over the surface of the covering was studied by means of a differential pressure gage with a piezometer and pitot tube attached to it.

18 The first test was made with a 3-in.-thick magnesia covering

on the test pipe, a temperature difference of 460 deg. fahr. between the pipe and the wind, and a wind velocity of 30 m.p.h. Under this condition the loss was 0.430 B.t.u. per sq. ft. of pipe surface per deg. fahr. temperature difference per hr. Under normal conditions of still air the loss was 0.302 B.t.u. This shows an increase of about 40 per cent due to the wind velocity. From a theoretical consideration of the question, it can be shown that the maximum possible increase of loss due to wind will be reached when the temperature below the surface of the canvas covering on the magnesia is reduced to the temperature of the wind itself.

19 The curve of Fig. 10 shows the temperature beneath the canvas for any condition of loss in still air. When calculations are being made for exposed pipes, the loss should be calculated both by

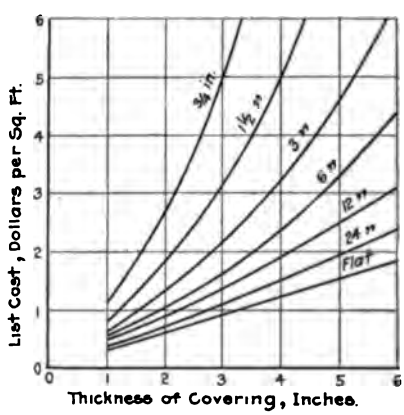


FIG. 15 COST CURVES FOR DIFFERENT-SIZED PIPES

use of this curve as explained before and by using the temperature of the pipe and the temperature of the air for T_1 and T_2. By comparing the loss in still air and the maximum loss which may be caused by wind, an idea of the probable increase due to exposure can be obtained and extra thick insulation applied accordingly. Curves are being worked out to show the percentage increase in loss at various different wind velocities and different temperature differences.

PERMANENCY OF INSULATING QUALITIES OF COVERINGS

20 The last important point in considering pipe coverings is the permanency of their insulation value. Tests were made on several old magnesia coverings. Fig. 14 shows the conductivity of a 1-in.-thick covering which had been in service at the Armour Glue Works

in Chicago for 8 years. The conductivity was slightly lower than the average of the new 1-in. coverings tested, showing that no deterioration in service had taken place. Several sections were obtained which had been saturated with oil. Tests on these showed much lower insulation values than new coverings. The damage was permanent and shows that care should be used to protect coverings from oil while in service.

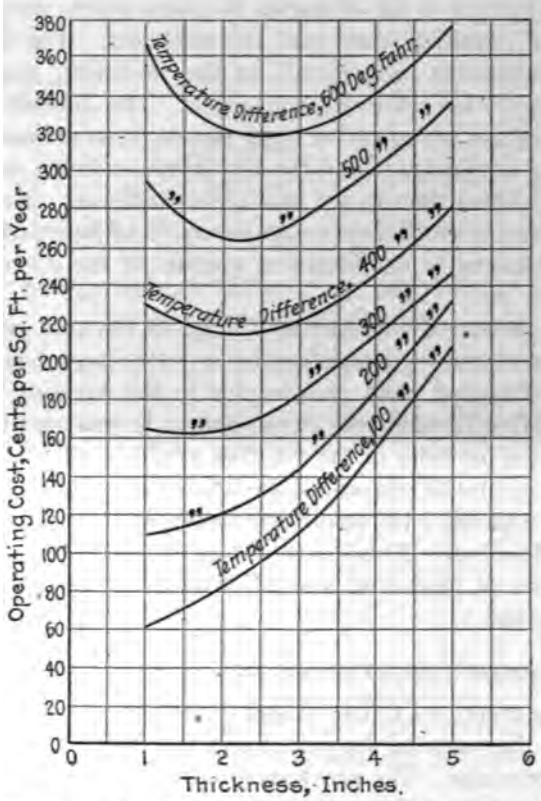


FIG. 16 CURVES FOR ¾-IN. PIPE — STEAM COST, 80 CENTS PER 1,000,000 B.T.U.

21 After considering the technical and theoretical side of heat losses from bare and covered surfaces, the next point is the economic side of the problem. In most cases the result desired is the maximum net saving of money for any given condition. If the covering cost were nothing, the proper thickness would be limited only by the requirements of space available, as each increased thickness would result in some slight increased saving in heat. In a practical case

where the covering has a finite cost, a point is soon reached where the increased cost of the covering would be greater than the additional saving in heat effected. The determining of this point is the thing in which the user of coverings is interested, as it is just at this point that the maximum net saving is accomplished.

INITIAL COST OF COVERINGS

22 In Fig. 15 a set of curves is given which shows how the list prices of coverings vary with the thickness. For flat surfaces the price is directly proportional to the thickness, starting at 30 cents per sq. ft. for coverings 1 in. thick. The difficulty of manufacture of molded coverings for pipes results in an increased cost per sq. ft. for a 1-in. thickness and the cost increases much more rapidly with the thickness than in the case of flat surfaces. More material is also required in molded coverings per sq. ft. of pipe surface than in the same thickness in flat blocks on account of the curvature of the surface.

23 By means of the curves of Fig. 16 the cost per sq. ft. of surface covered can be determined for any thickness desired. From this cost the annual fixed charges due to the covering can be calculated. After considerable investigation it was decided that 20 per cent of the list price of the covering would be allowed as the cost of application, and 13 per cent of the total cost as the annual charges (6 per cent interest, 5 per cent depreciation and 2 per cent insurance and miscellaneous). This fixed charge was calculated for seven different sizes of pipes and five different thicknesses, based on list cost of covering.

OPERATING EXPENSES DUE TO HEAT LOSSES

24 The other cost to be charged to the operating expenses of the covering is the value of the heat losses through the different thicknesses of coverings. The previous work done on measuring the loss through 15 samples of magnesia furnished the necessary data for calculating the loss in heat units. After the heat loss was determined it was necessary to convert the loss into dollars and cents. The assumptions used in making this conversion were that the cost of coal is 75 per cent of the cost of steam, that 1 lb. of coal as burned will evaporate 7 lb. of water from and at 212 deg. fahr., and that each pound of steam contains 1000 B.t.u. above the feedwater temperature. The value of the heat losses was calculated for seven sizes of pipes, five temperature differences between pipe and air,

and four different costs of heat, both on the basis of a known cost per million B.t.u. and on a cost per ton of coal and the average conditions of steam generation given above. By making these calculations both ways, the results are applicable to plants where the steam costs are accurately known, as well as to those where accurate records are not kept.

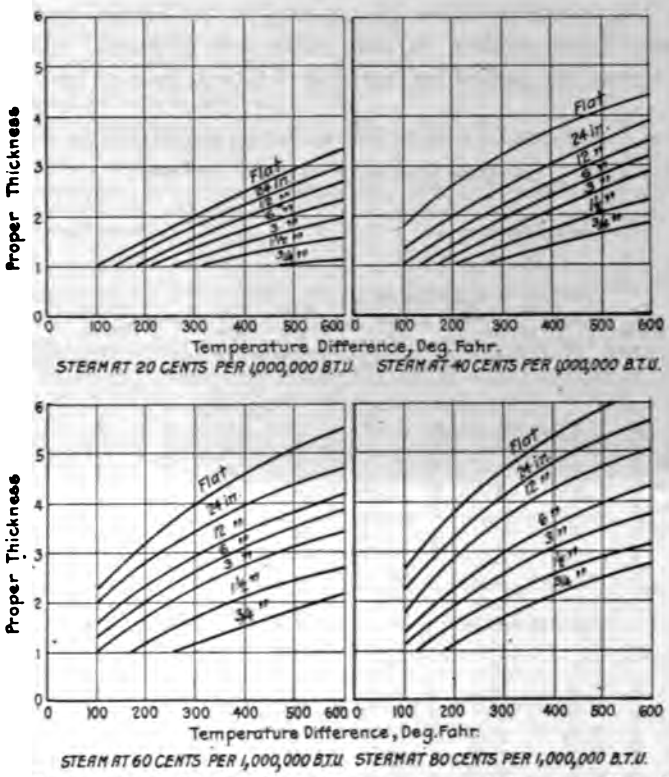


FIG. 17 THICKNESS OF 85 PER CENT MAGNESIA FOR MAXIMUM NET SAVING

25 By combining the fixed cost and the heat losses per sq. ft. per year, the total operating expenses were obtained. Once these are obtained, it is simply a matter of picking that thickness which gives the minimum annual operating expense to obtain the proper covering to use. It is evident that the thickness which gives the minimum operating expense also gives the maximum net saving, as the loss from bare pipe is a constant under given conditions and the net saving is the difference between the operating expense and the loss from bare pipe.

SELECTION OF COVERINGS TO GIVE LOWEST OPERATING EXPENSE

26 The way in which the covering which gave the lowest operating expense was chosen was to plot curves of the type shown in Fig. 16 for the total operating expense for five different thicknesses. By selecting the thickness corresponding to the lowest point on each curve, the proper thickness of covering to use for the temperature difference corresponding to that curve was obtained. One set of these curves was plotted for each size of pipe at each of four different

TABLE 2 THICKNESS OF 85 PER CENT MAGNESIA FOR MAXIMUM NET SAVING

Thickness in Inches. S = Standard Thickness

Coal at $2 per Ton						Coal at $4 per Ton					
Size Pipe, Inches	Hot Water, 175° F.	Steam, 5 Lb.	Steam, 100-200 Lb.	200 Lb. 150° F. Superheat	200 Lb. 300° F. Superheat.	Size Pipe, Inches	Hot Water, 175° F.	Steam. 5 Lb.	Steam, 100-200 Lb.	200 Lb. 150° F. Superheat.	200 Lb. 300° F. Superheat.
¾	S	S	S	S	S	¾	S	S	S	1½	2
1½	S	S	S	S	2	1½	S	S	1½	2	2
3	S	S	S	1½	2	3	S	S	2	2	3
6	S	S	1½	2	2	6	S	S	2	3	3
12	S	S	2	2	3	12	S	S	3	3	4
24	S	S	2	3	3	24	S	S	3	4	4
Flat	¾	1½	2	3	3½	Flat	2	2	3	4	4½
Coal at $6 per Ton						Coal at $8 per Ton					
¾	S	S	1½	2	2	¾	S	1½	1½	2	3
1½	S	S	1½	2	3	1½	S	1½	2	3	3
3	S	1½	2	3	3	3	1½	2	3	3	4
6	S	2	2	3	4	6	1½	2	3	4	4
12	1½	2	3	4	4	12	2	3	3	4	5
24	2	3	3	4	5	24	2	3	4	5	6
Flat	2½	3	4	5	5½	Flat	2½	3½	4½	5½	6½

steam costs. From this set the thickness curves given in Fig. 17 were derived, and from the thickness curves Table 2, showing the proper thickness in relation to coal cost per ton, was obtained by making the assumption previously explained.

27 From these curves and tables the proper thickness to use in order to obtain the maximum net saving under any condition may easily be determined.

LE 3 COAL SAVED BY 85 PER CENT MAGNESIA COVERING 1 INCH THICK

n Pressure	Saturated, 5 Lb.	Saturated, 10 Lb.	Saturated, 50 Lb.	Saturated, 100 Lb.	Saturated, 150 Lb.	Saturated, 200 Lb.	200 Lb. Pressure with 100 Deg. Superheat
m temperature, deg. fahr.	228	240	298	338	366	388	488
ı. loss per hr. per sq. ft. bare pipe	367	409	625	802	937	1058	1735
ı loss per hr. per sq. ft. of pipe covered ih 85 per cent magnesia	69	76	105	126	142	153	210
ı. saved per hr. per sq. ft. by covering e with 85 per cent magnesia	298	333	510	676	795	905	1525
ı (2240 lb.) coal saved per 10,000 sq. ft. r year of 8760 hr. by pipe covered with per cent magnesia	1190	1330	2080	2700	3180	3620	5650
of coal saved per year, as above, at tons per car	30	36	52	68	80	90	140

oal efficiency taken at 14,000 B.t.u. per lb. with boiler efficiency at 70 per cent.

LE 4 MONTHLY COAL SAVING, IN DOLLARS AND CENTS, BY THE USE OF 5 PER CENT MAGNESIA PIPE COVERING, STANDARD THICKNESS, PER 100 LINEAL FT. OF STEAM PIPES

ze of Pipe, Inches	5 Lb. Steam Pressure	10 Lb. Steam Pressure	50 Lb. Steam Pressure	100 Lb. Steam Pressure	150 Lb. Steam Pressure	200 Lb. Steam Pressure	200 Lb. Steam Pressure, 100° Superheat
½	1.44	1.58	2.20	3.28	3.66	4.11	6.80
¾	1.72	1.89	2.87	3.70	4.26	4.89	8.03
1	2.11	2.30	3.56	4.80	5.35	6.04	10.00
1¼	2.52	2.74	4.22	5.52	6.50	7.25	12.20
1½	2.86	3.10	4.73	6.14	7.29	8.17	13.70
2	3.53	3.74	5.86	7.63	8.93	10.11	16.80
2½	4.25	4.39	6.95	9.07	10.55	11.90	19.90
3	5.00	5.33	8.30	10.90	12.60	14.30	23.82
3½	5.72	6.22	9.60	12.40	14.40	16.32	27.23
4	6.50	7.06	10.60	14.05	16.40	18.40	30.85
4½	7.30	7.69	11.80	15.35	17.92	20.25	34.00
5	7.97	8.64	13.16	17.20	20.00	22.72	38.00
6	9.36	10.15	15.60	20.38	23.82	26.88	44.90
7	10.90	11.70	18.38	23.68	27.60	30.80	52.00
8	12.26	13.22	20.40	26.60	31.20	34.90	58.55
9	13.80	14.70	22.70	29.00	34.52	38.61	64.80
10	15.08	16.33	25.00	32.70	38.40	43.08	72.40
surface, area sq. ft. 1½ in. ck.	5.26	5.67	8.80	11.50	13.48	15.12	25.44

hese savings are based on pipes carrying steam for 24 hours per day and 30 days per month. Coal ured at $5 per ton (2000 lb.) delivered. Combined efficiency of furnace and boiler, 70 per cent. n temperature, 75 deg. fahr.

28 The saving in coal tonnage and car capacity accomplished by applying 1-in.-thick coverings to 3-in. pipe is shown in Table 3. The savings are calculated for pressures from 5 lb. per sq. in. to 200 lb. per sq. in. and 100 deg. fahr. superheat. They vary from 30 carloads at the lower pressure to 140 carloads at the higher pressure for every 10,000 sq. ft. of exposed surface.

29 In Table 4 the saving is expressed in dollars and cents per hundred lineal ft. of pipe per month when covered with "standard" thick coverings and where coal costs $5 per ton. In this case the saving varies from $1.44 for 100 ft. of ½-in. pipe at 5 lb. pressure to $72.40 for 100 ft. of 10-in. pipe at 200 lb. pressure and 100 deg. fahr. superheat.

TESTS OF BOILERS WITH AND WITHOUT COVERINGS

30 In order that the results of the laboratory tests might be checked on a larger scale, several practical tests were made. The first and most important of these was a boiler test made at a mine in Bruceton, Pa. There were two boilers in the plant, of 80 and 60 hp., locomotive type. The exposed surface on these boilers was 675 sq. ft. The tests covered a period of 24 hours. Conditions of load, etc., were practically the same during both tests. During the first test, while the boilers were uncovered, 10,784 lb. of coal was burned to evaporate 58,000 lb. of water. In the second test, after the boilers had been covered with 2 in. of 85 per cent magnesia blocks and plastic, 9296 lb. of coal was burned to evaporate 59,500 lb. of water. The evaporation rate during the first test was 6.35 lb. of water from and at 212 deg. fahr. per lb. of coal as fired, and during the second 7.55 lb.; 1500 lb. more water was evaporated with 1488 lb. less of coal burned. If calculated for an equal evaporation of water, the saving in coal would be 1700 lb. per day. The calculated saving based on the laboratory experiments was between 1400 and 1500 lb. per day. This saving amounts to 15 per cent of the coal burned due to covering the boiler alone, as the pipe lines were not included in the test. (The results of this test were reported in detail at the 1918 Spring Meeting of the Society. See p. 400, *ante*.

31 A test is now in progress to ascertain the saving due to covering a gas hot-water heater. This will be reported later.

32 It is hoped that the data here presented will be of assistance to engineers and will help in the conservation of the resources of our country.

DISCUSSION

L. B. McMillan (written). The method employed by the author in making his tests was one of undoubted accuracy if successfully carried out. Therefore he is to be complimented on his work, as the writer is familiar from his own experience with the difficulties encountered in making tests of this kind.

In Fig. 1 the author shows results of various investigations on the rate of heat loss from bare pipe and he concludes that Paulding's curves give the best average value. The writer does not believe that existing experimental data bear out Paulding's estimated values, which seem to show such a wide variation between losses from pipes of various sizes. It is to be expected of course that the rate of loss should be greater from pipes of small diameter than from larger ones, but the writer does not believe the differences are as great as Paulding's curves would seem to indicate.

Fig. 18 shows results of tests by a number of investigators and the close agreement of these figures seems to show that the size of pipe has much less effect than Paulding's curves would indicate. For example, Barrus' results for 10-in. pipe are only slightly lower than his results for 2-in. pipe, and for a comparison of this kind results by the same investigator are to be preferred as other variables than the one being considered are less likely to be present.

The values given by Chr. Eberle show that the larger pipe has the greater rate of loss, which is just the opposite of what we would expect. This result, however, is partially explained by the fact that the room temperature was about 20 deg. fahr. higher during the tests of the large pipe than during those of the smaller one, and it has been shown that the rate of loss is dependent upon the absolute temperature as well as upon the temperature difference.

Now, returning to Paulding's curves, his results are founded on Péclet's work, but referring to results of more modern tests by Barrus, Brill, Norton and Jacobus, he calculated that Péclet's radiation coefficient of 0.64 for iron surfaces was much too low and that it should be about 0.87. The lowest curve in Fig. 18 represents the results calculated from Péclet's coefficients as given in Kent, and this shows that those coefficients or some of them must have been too low.

It is now pretty well established how great these losses from uninsulated surfaces are. For example, it has been shown in Cir-

cular No. 17 of the Engineering Experiment Station of the University of Illinois that the annual loss from 100 ft. of 5-in. bare pipe carrying steam at 150 lb. pressure amounts to 2 cars of coal and 12 tank cars of water. Few would leave such a length of pipe uninsulated, but there are many flanges, fittings, short lengths, etc., which they do leave uninsulated.

Very little surface is required to lose the heat equivalent to a ton of coal in a year, as will be seen from Table 5. For example, even at atmospheric pressure it requires only about 7 sq. ft. of surface and at 100 lb. less than 3 sq. ft. of surface to waste a ton of coal in a year. Therefore even one pair of 10-in. flanges without insulation represents a loss of a ton of coal per year.

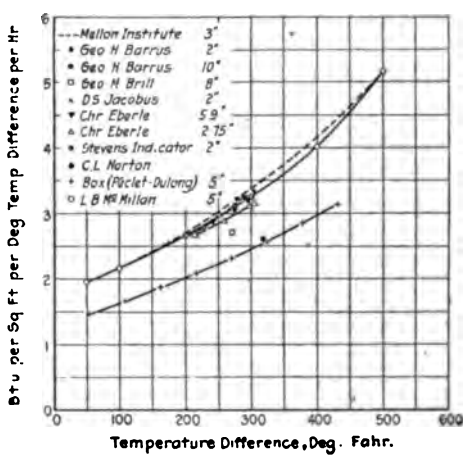


FIG. 18 HEAT LOSS FROM BARE PIPE

The author's conclusion in Par. 18 that the maximum effect of wind velocity is to reduce the surface temperature of the insulation to the temperature of the air itself, is in accordance with the writer's views on this subject as demonstrated by actual experiment and expressed in a discussion at the 1917 Annual Meeting of the Society. However, in the example given in Par. 18 it is difficult to account for the very large increase in heat loss, as with 3-in. magnesia covering the surface resistance is less than 15 per cent of the entire resistance; therefore, removing this entirely should not cause a 40 per cent increase in the rate of heat loss.

E. C. FREELAND (written). Here in Louisiana there is an enormous heat loss in cane-sugar factories, due to the fact that the greater

part of the piping in them has no covering of any kind. To give an idea of the amount of this loss, Kerr has found that in a factory grinding 1200 tons of cane per 24 hours there are 2000 sq. ft. of pipe surface for low-pressure steam and 3000 sq. ft. for high-pressure steam, and that there is a loss of 1.83 gal. of fuel oil per ton of cane,

TABLE 5 HEAT LOSSES FROM UNINSULATED HOT SURFACES

Ordinary steam temperatures; temperature of surrounding air, 70 deg. fahr.

Steam pressure (gage), lb.	Steam temperature, deg. fahr.	Difference betw. temp. of steam and surrounding air, deg. fahr.	Loss per sq. ft. per hr., B.t.u.	Waste of coal in lb. per sq. ft. per year	No. of sq. ft. of surface that wastes ton of coal in 1 yr
0	212	142	334	293	6.82
10	240	170	425	372	5.38
25	267	197	522.5	458	4.37
50	298	228	644	564	3.55
75	320	250	737.5	646	3.10
100	338	268	820	718	2.79
150	366	296	960	840	2.38
200	388	318	1079	945	2.12
250	406	336	1184	1036	1.93

Temperatures lower than 212 deg. fahr.

Surface temperature, deg. fahr.	Dif. betw. temp. of surface and surrounding air, deg. fahr.	Heat loss per sq. ft. per hr., B.t.u.	Waste of coal in lb. per sq. ft. per year	No. of sq. ft. of surface that wastes 1 ton of coal in 1 yr.
100	30	56.6	49.6	40.3
120	50	97.5	85.4	23.4
140	70	142	124.3	16.1
160	90	190	166.3	12.03
180	110	242	212	9.44
200	130	298.5	261.5	7.65

Above figures involving waste of coal are based on the following:

10,000 B.t.u. available per lb. of coal, which is equivalent to a boiler efficiency of 70 per cent, using coal with an assumed heating value of about 14,000 B.t.u. per lb.

These figures are very conservative, as both the boiler efficiency and the heat value of the coal are high — a lower boiler efficiency or inferior grade of coal would cause even a greater waste in pounds of fuel.

due to uninsulated piping. Hind estimates that in an 1800-ton factory there is a loss of 100 boiler hp. due to uninsulated piping, while Noel Deerr points out that there is a 5 per cent loss of the total steam generated by the bagasse in a factory having no insulated piping. These figures are given to show the heat losses due to radia-

tion in a single industry, and no doubt there are other industries in which heat losses due to radiation from pipes are as great, if not greater.

The author's tables showing the saving due to pipe coverings should prove of great value, especially Table 2, because of their completeness and condensed form.

L. R. INGERSOLL[1] (written). One conclusion which may be readily drawn from the tables and curves of the paper, and which I should like to see emphasized, is that added thicknesses of covering are relatively much more effective on large pipes than on small. In a recent installation which I have in mind it was desirable to keep the basement through which most of the steam pipes ran as cool as possible, and this was done by specifying double covering on all pipes whether 1-in. or 6-in. While a little cost calculation might be necessary to establish the fact, it is almost obvious that it would have been better to omit the second covering on the smaller sizes of pipe and spend the money saved in extra lagging on the larger mains.

F. M. FARMER (written). At the Electrical Testing Laboratories we have done a considerable amount of testing of commercial steam-pipe coverings, and within the last few weeks completed some tests on a number of coverings up to 800 deg. fahr. pipe temperature. In these tests we used the method originated by the late H. G. Stott, with, however, certain important changes which eliminated the principal objections to that method, namely, the long length of pipe employed to minimize the end effects and the large currents required.

Each sample consisted of enough covering to cover one standard length of 3-in. pipe — about 18 ft. The heat was supplied in the form of alternating electrical energy expended directly in the pipe, and temperatures were measured with thermocouples distributed along the surface of the pipe. The end effects were eliminated by increasing the temperature at the ends of the pipe by means of a variable amount of resistance introduced in the circuit at those points. These resistances were adjusted until the temperature was the same near the ends of the pipe as at the middle. Under these conditions there is, of course, no longitudinal flow of heat, and the heat loss from a definite length of the covering is obtained by simply measuring

[1] Professor of Physics, University of Wisconsin, Madison, Wis.

the watts dissipated in that length of pipe. In these tests measurements were made over a 6-ft. length and an 8-ft. length at the middle of the pipe.

The use of alternating current rather than direct current simplifies this method very much. Not only are the necessary currents to give the desired temperatures much smaller, but a step-down low-voltage transformer can be used close to the pipe, thus simplifying the wiring from the source of power. The measurement of alternating-current power is now a simple matter with modern reflecting dynamometer types of wattmeters.

The advantage of more uniform pipe temperature is obtained if the heat is supplied to an intervening medium between the electric heater and the pipe. This medium was oil in Mr. McMillan's tests and air in the author's tests. In our tests, where the electrical energy was supplied directly to the pipe, we have found slight differences in the temperature due apparently to slight variations in the electrical resistance caused by either slight variations in the thickness or in the composition of the pipe. While for very precise work this might constitute an objection to this method of testing, the fact is that for commercial testing the results are entirely satisfactory. As a matter of fact, there is no justification for attempting to get extremely precise results in work of this character because of differences between different specimens of the same sample due to the inherent variations in the material, in the thickness and in the physical condition. And when it comes to the practical application of the data the variables which enter are still larger, so that for commercial purposes there is a little justification for extreme refinements in measurements of this class. Incidentally, however, it is interesting to note that the curve obtained for one of the coverings just tested by the modified Stott method, which was a 2-in. magnesia covering, checks almost exactly with the corresponding curve in Fig. 5 of the paper.

A. G. Christie (written). The writer would have liked to have seen some discussion in the paper itself of the heat losses from flanges and from the bonnets of valves. Very little information is available as to the nature and amount of such losses and of the efficiency of the various coverings used on these parts. Many plants have dozens of uncovered flanges, and very often no attention is paid to the covering of valve bonnets. The heat losses must be enormous in many cases.

The writer had charge of a long high-pressure steam line for several years. It was noted that there were far fewer failures of gaskets where the joints were well covered than where these were bare. Objection is frequently raised that covered flanges make renewal of gaskets difficult. Our experience has been that such renewal was not so frequently necessary with covered flanges as with bare joints. Both solid molded flange joints and blocked and plastered joints were used. The latter proved the cheapest, best and most serviceable in the long run.

The writer has also noted that the heat-insulating properties of various plastic cements used to smooth up blocked work vary over a wide range, but these materials invariably are poorer insulators than the magnesia blocks. Some results of research on these cements would be of value to engineers as a guide in preparing pipe-covering specifications.

The author apparently used merely plain canvas-covered insulating materials. Pipe lines are frequently painted various colors in power plants with various kinds of paint and tar preparations. Some are even enameled or waterproofed. What is the effect of such treatment, and have the various colors any appreciable effect on radiation?

The writer has had difficulty with mildew on steam-heating pipe lines in underground tunnels and conduits during summer months when steam is off. This mildew soon destroys the canvas and allows the covering to fall off. The trouble was completely stopped by painting the covering with silicate of soda. What effect does this substance have on heat transfer?

It is thus apparent that the author has started on a line of research with almost an infinite number of problems ahead, and yet all of them are of prime importance in engineering work. Let us hope that we may hear from him again as further valuable data are available.

Wm. T. Magruder (written). Attention should be called to the apparent fact, as shown in Fig. 16, that for $\frac{3}{4}$-in. pipe, with steam costing 80 cents per 1,000,000 B.t.u., and with a temperature difference of 300 deg. fahr., the operating cost is the same whether the thickness of the covering is 1 in. or 2 in. However, this does not seem to agree with the data given in Fig. 17.

Referring to Pars. 17 and 18, it is to be noted that when the flow of air was along the surface at a wind velocity of 30 m.p.h., there

was an increase of about 40 per cent in the heat lost through a 3-in.-thick magnesia covering. In much practice, wind usually blows through windows and doors normal to the pipes rather than along them, and at speeds which are less than 30 m.p.h. It would be valuable to obtain data showing the relations of the losses when the air was driven at different speeds and in directions both along and at right angles to the bare and covered pipes.

The losses reported in the paper are those from what may be called "dry and quiet heat" within the pipes. In most engineering practice where 85 per cent magnesia pipe coverings are used, the content of the pipes is wet steam flowing at high velocities. It is well known that more heat is lost per unit of surface and more steam condensed in a pipe carrying wet steam than in one carrying dry, or even slightly superheated, steam, all at the same temperature, and in a pipe carrying steam at the usual velocities of practice as compared with a pipe containing quiet or stagnant steam. It would therefore seem that the interesting results recorded in this paper hardly apply to ordinary engineering practice for steam flowing in pipes at high velocities, and it is to be hoped that the same careful experimentation will be extended to pipe coverings for pipes carrying superheated and wet steam at the ordinary velocities commonly found in practice.

H. N. Dawes said that the curves of Fig. 14 showing the relative efficiency of old and new 85 per cent magnesia coverings bore out his own experience covering 20 years. He had also found that the coverings themselves did not deteriorate with use.

So far as he knew, tests had never been made to determine the effect of greatly increased velocity of steam flow in the pipe on the heat losses, and he trusted the Mellon Institute might find it possible to investigate this matter. Data on the insulating value of plastic magnesia covering were also needed, as on account of the great number of irregular fittings, bonds, flanges and apparatus on which this was used it sometimes happened that in a plant the surface area covered with plastic magnesia was greater than that protected by sectional covering.

B. F. Tillson asked the author whether he could give any information as to the heat losses for temperature differences of 800 to 1400 deg. fahr. These differences were quite unusual, it was true, but he had encountered them in his work and had found that

the losses seemed extraordinarily large as compared with those for lower temperature differences.

THE AUTHOR. Referring to the effect of wind velocity on the loss from the covering, which has been discussed by Messrs. McMillan and Magruder, I would say that at the time the paper was written the experiments on wind velocity had just begun, and the figures given therein were the first obtained. It was found there was a large amount of filtration unless the surface was protected with something which would prevent the entrance of the air going through the tunnel. It was also found that with the wind traveling 30 miles an hour, a trifling crack in the covering would triple the loss. As there is a crack between two sections, it will be seen that the air will circulate through and carry away a great deal of heat.

Later tests have shown a maximum increase due to wind velocity of about 20 per cent when the magnesia insulation had an outer covering (of sheet iron) which prevented circulation of air currents through the cracks. This agrees fairly well with the calculated value.

In reply to Mr. Tillson, it is to be said that some experiments have been made with temperature differences up to 800 deg. fahr., and that these have yielded results showing that the curves given in the paper can be safely extended to higher temperature differences.

As to Mr. Dawes' question regarding steam velocity, the loss from the pipe is practically independent of the velocity of the steam in the pipe. That is, the only effect is in the temperature of the pipe, which is not sufficient to greatly influence the loss. The quantity of heat transmitted through the pipe depends on the velocity of the steam, and as the loss from the pipe is nearly independent of the velocity, the efficiency of transmission increases as the velocity increases.

No. 1661

THE CHEMICAL AND PHYSICAL CONTROL OF BOILER OPERATION

INCLUDING THE APPLICATION OF SIMPLE FORMULAE FOR ESTIMATING THE HEAT-LOSS ITEMS, ETC.

By E. A. Uehling, Passaic, N. J.
Member of the Society

The economical status of a boiler plant can be approximately determined by either of two methods: (a) the mechanical method, based on the heat utilized; and (b) the chemical and physical method, based on the heat wasted. In the former, reliance is placed on the coal weigher and the water meter or steam-flow meter; in the latter the CO_2 meter and pyrometer are used.

The author discusses the advantages and disadvantages of both methods and shows that while each is necessary for complete results, the chemical and physical method gives more directly useful information. He emphasizes the facts that no wholesale method is adequate; that every boiler must be treated individually and that it must be known what every boiler is doing all the time and adjustments made to keep the results right.

Examples are given of the application of information shown by charts from recording instruments to control of firing. The reliability of the chemical method of control is discussed at length. The author then shows by actual numerical examples the application of formulæ which he has derived to data taken from autographic records of CO_2.

THE importance of fuel conservation is now so thoroughly understood by engineers that nothing further need be said about it here. As to the best method for attaining the end there is still much diversity of opinion and, therefore, room for profitable discussion.

2 The value of a fuel depends on the heat it contains, and the value of the heat depends on the degree of its utilization. The heat contained in coal is liberated by the chemical process of combustion, hence combustion efficiency is the prime requisite for the economic utilization of fuel. This is especially true in the application of heat to the steam boiler.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

3 Before intelligent steps can be taken to bring a given boiler plant to its maximum efficiency, it is necessary to know with what efficiency the plant is working. Scientific refinement is not necessary in every-day practice, but *scientific reasoning must be applied*, and the data upon which reasoning can be based must be continuously observed and, wherever possible, autographically recorded.

METHODS OF CONTROLLING BOILER-PLANT OPERATION

4 The economical status of a boiler plant can be ascertained by either of the two distinct methods, viz:

a The mechanical method, based on the heat utilized.

b The chemical and physical method, based on the heat wasted.

5 The mechanical method relies on the readings of the coal weigher and the water meter or steam-flow meter. If the heat value of the fuel is known, the data obtained by these appurtenances enable one to calculate roughly what percentage of the heat in the coal fired is utilized in making steam. For obvious reasons the results cannot be calculated oftener than once a day and generally once a week is considered sufficient for a control over the operation of the boiler plant. Aside from the lateness in getting the desired information, this method suffers in accuracy and reliability as a control from the following errors and shortcomings:

a The coal weigher cannot discriminate between coal and ash and moisture, and since these constituents are never constant and frequently vary five per cent or more in successive shipments, and since the heat value of the fuel depends on its purity, the calculated results will be that much in error.

b The water passed through the meter is not all evaporated. An appreciable amount may be carried over with the steam, more may be lost through leaky blow-off cocks, and considerable is wasted by blowing off the boilers, which is not only not accounted for but actually appears on the credit side

c The steam may be superheated

d The feedwater temperature may vary appreciably.

Thus we see that a water meter and coal weigher can give only a rough, wholesale control unless supplemented by scientific instruments and observations. The mechanical control has another and

even more serious shortcoming in that it gives absolutely no clue as to why the plant as a whole is operating more or less wastefully.

6 The chemical and physical method has the following advantages over the mechanical method:

a It can be more easily and cheaply installed

b The records show up the operation of the boilers continuously instead of only at the end of longer or shorter periods; one day at best

c It shows up the combustion and absorption efficiency factors separately so that the proper steps to improve the efficiency of the plant can be promptly and intelligently taken

d The value of its records is not affected by a variation in ash or moisture content of coal burned. Nor is the record affected by the waste of feedwater or the variation in its temperature.

7 *To attain maximum collective boiler efficiency every boiler must be treated as an individual.* To be under proper economic control both its combustion and absorption efficiencies must be under constant observation. Maximum boiler efficiency cannot be maintained without *knowing what every boiler is doing all the time.* To this every combustion and boiler expert will agree; but opinions will no doubt differ as to the best means for effecting this constant observation. It would appear obvious that the most direct way is the best way. Combustion is a chemical phenomenon and should therefore be most effectively controlled by chemical means. Absorption is a physical phenomenon and is best controlled by physical means. The two principal instruments of observation are the CO_2 meter, a chemical instrument, and the pyrometer, which is a physical instrument. As a necessary auxiliary the double differential draft gage is required. Boiler draft and furnace draft are essential elements in the proper control of combustion and should be observed separately.

8 The author has stated on another occasion that a proper slogan for the engine room would be, *Watch your adjustments and keep them right and your results will be right;* whereas for the boiler room the slogan should be: *Watch your results and change your adjustments to keep the results right.* There is no such thing as a fixed adjustment in the operation of a boiler. The rate of combustion must be changed to keep the steam pressure right, the draft must be changed to keep the rate of combustion right, and the thickness of fire must be

changed to keep the efficiency of combustion (per cent of CO_2) right. As the fuel and ash bed thickens a stronger draft is necessary to keep the required rate of combustion, and there are numerous minor varieties which require changes in the draft adjustments if combustion efficiency and the required boiler capacity are to be maintained, i.e., maximum CO_2 and a uniform steam pressure.

INSTRUMENTS RECORDING DRAFT, CO_2 PERCENTAGE AND ESCAPING GAS TEMPERATURE NECESSARY FOR CONTROL OF FIRING

9 To insure these results CO_2 as well as boiler and furnace draft indicators must be placed at or near the boiler front within easy view of the fireman and in close proximity to the draft-regulating wheel or lever. The CO_2 meters, pyrometers and boiler draft gage should be autographic-recording. In small and moderate-sized plants the recording gages should be placed in the engine room where they are under easy observation by the operating engineer. In large plants that can afford a control engineer, other arrangements will suggest themselves.

10 With such an outfit on every boiler the firemen have before them at all times the information necessary for intelligent and effective control of their fires, *if properly instructed how to apply this information.* The steam gage tells them when to increase or decrease the rate of combustion. The boiler draft tells them whether the air supply is right for the required rate of combustion. The CO_2 indicator tells them whether the thickness of the fire is right and the furnace draft indicates the condition of the fire. The volume of air required to burn a unit weight of combustible with maximum combustion efficiency varies with the kind of fuel, construction of furnace and method of stoking, but for any given set of conditions a definite volume of air will consume a definite maximum weight of fuel completely. Since the boiler draft is a fair index to the rate of the air supply it is the proper basis for regulating the rate of combustion, and the rate of fuel supply must be increased or decreased to produce maximum combustion efficiency, to which CO_2 is the index.

INFORMATION AFFORDED BY RECORDING-INSTRUMENT CHARTS

11 The three autographic records, namely, those of CO_2, temperature of the escaping gas and the boiler draft, preferably on one chart, give the engineer in charge the following information at a glance:

a Whether normal combustion efficiency has been maintained; and if not, the precise time when it became abnormal and how long it remained so. This enables him to inquire into the cause, with the confidence born of knowledge, and to apply the proper correction. The continuous record further reveals in hand-fired boilers how often the fires were replenished, how long the fire doors were left open, when the fires were cleaned and how long it took to clean them. In stoker-fired boilers changes in handling the fire are similarly revealed

b The temperature record shows whether the absorption efficiency has continued normal; if not, the variation may be due to necessary variations in the rate of driving, and if so this will be revealed by the record of the boiler draft, which is an index to the rate of driving. Or it may be due to a breaking-down of the baffling, which is also instantly revealed by the boiler draft. The mucking-up of the heating surface is indicated by a gradual increase in the temperature of the escaping gasses

c The record of the boiler draft, in addition to its contributing value to the pyrometer record, becomes in combination with the per cent of CO_2 a very good index to the rate of combustion, as the writer will endeavor to show later.

EXAMPLES OF APPLICATION OF INFORMATION GIVEN BY CHARTS TO CONTROL OF FIRING

12 If these three records are all made on the same chart they can be readily integrated by means of the polar planimeter and the heat carried to waste by the dry gases quickly calculated by the formula developed in the Appendix, as illustrated by several examples given further on. *Autographic boiler records, like steam-engine indicator cards, are of no value unless they are regularly scrutinized and correlated and the information they give promptly and intelligently applied.* If the three essential records are all on the same chart this is neither difficult nor laborious.

13 Fig. 1 illustrates sections of such charts showing various relations of these three records to each other. The CO_2 records shown in Secs. 1 and 2 are facsimile samples of records from a boiler of the Manning type burning No. 1 buckwheat coal. Sec. 1, made when the recorder was first installed, shows that the firing was irregular and that the coal bed was kept too thin, through which holes quickly

developed. The average CO_2 was scant 8 per cent. The reason for the low CO_2 being thus clearly revealed, the proper remedy at once suggested itself. The fireman was instructed to carry a little heavier fire and watch the CO_2 indicator, with the result shown in Sec. 2, which is a sample record for the same boiler after the fireman had been

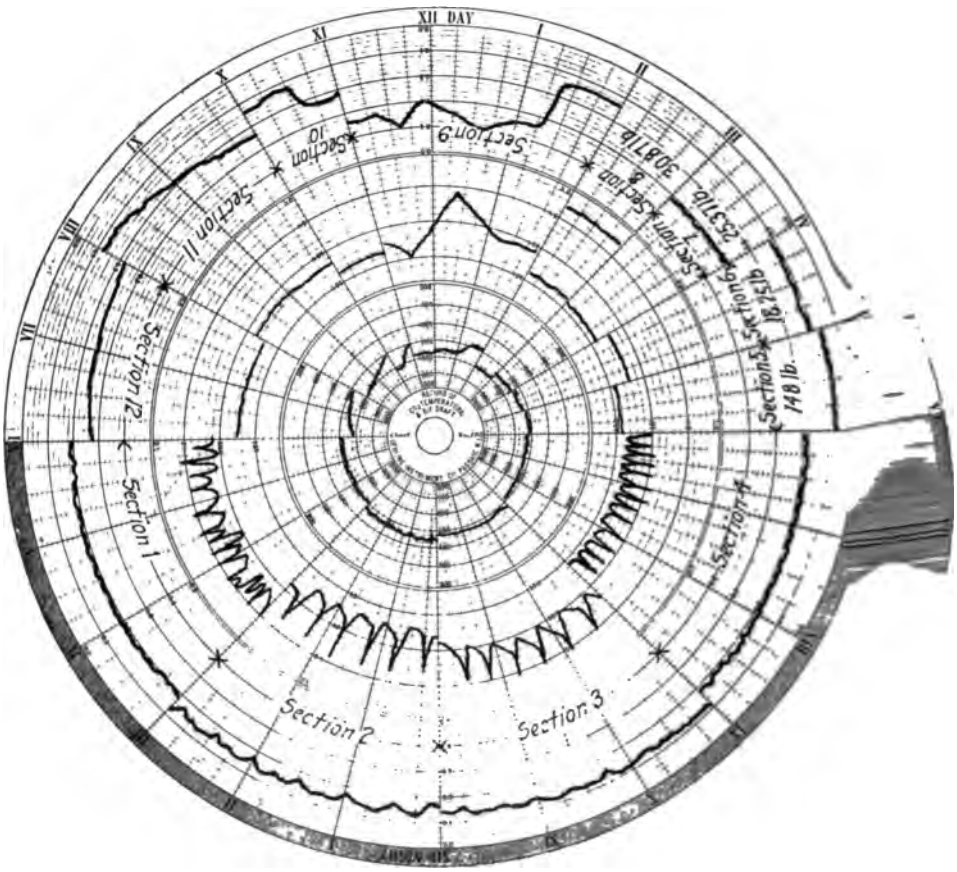


FIG. 1 CHART FROM ISTRUMENT RECORDING SIMULTANEOUSLY PERCENTAGE OF CO_2, STACK TEMPERATURE AND BOILER DRAFT UNDER VARIOUS CONDITIONS

instructed and had learned to be guided by the CO_2 indicator in adjusting the thickness of fire to the draft necessary to maintain the required steam pressure. So guided he had no difficulty in keeping the CO_2 at an average of about 12 per cent. Having the three principal records on the same chart their relation to one another is readily

erceived, and it will be seen at a glance that the boiler draft is about .08 in. higher under the conditions represented by Sec. 1 than those y Sec. 2, also that the temperature shown in Sec. 1 is about 25 deg. igher than in Sec. 2.

14 Applying Formula [4][1] to the facts recorded in Secs. 1 and 2 f Fig. 1, the sensible heat in the dry gases per pound of carbon urned, under the conditions shown by the CO_2 record in Sec. 1 is ound to be

$$L = \left(0.24 + \frac{58.46}{8}\right) \times 510 = 3850 \text{ B.t.u.}$$

nd for Sec. 2,

$$L = \left(0.24 + \frac{58.46}{12}\right) \times 460 = 2450 \text{ B.t.u.}$$

Therefore the heat carried off by the gases was [(3850 − 2450)/2450] × 100 = 57.5 per cent greater with uncontrolled firing than when ontrolled by the CO_2 indicator and recorder.

15 It will be noticed that the gases left the boiler at a tempera- ure 25 deg. higher when containing 8 per cent of CO_2 than when they ontained 12 per cent, which shows that absorption efficiency in- reases with combustion efficiency.

16 It will further be noticed that the boiler draft is about 0.12 n. with 12 per cent of CO_2 and fully 0.20 in. when only 8 per cent of CO_2 is present, which is due to the greater volume of gas per pound of arbon consumed. The relative volumes are respectively:

$$G_v = \frac{3192}{8} = 399 \text{ cu. ft.},$$

nd

$$G_v = \frac{3192}{12} = 266 \text{ cu. ft.}$$

17 Now since the boiler draft is an approximate index to the olume of gas produced per pound of carbon burned and CO_2 is a true ndex of the weight of carbon contained in this volume of gas, it ollows that if we multiply the boiler draft by the percentage of CO_2 he product will be an approximate index to the rate of combustion. Ve therefore find that the indices to the rate of combustion under the onditions as recorded in Sec. 1 and 2 were respectively 8 × 0.20 = .60, and 12 × 0.12 = 1.44.

18 This means that it was necessary to burn about [(1.60 − 1.44)/1.44] × 100 = 11 per cent more coal to keep up the steam with

[1] See Par. 65 in Appendix.

8 per cent of CO_2 than with 12 per cent, which corresponds very well with the improved results attained in the plant in which the records thus analyzed were produced.

19 Secs. 3 and 4 of Fig. 1 show records representing a water-tube boiler burning bituminous coal. Sec. 3 illustrates conditions before, and Sec. 4, after, control by aid of CO_2. A glance at the CO_2 record will show that the fires carried were too thick. The low percentage of CO_2 (about 8.75 per cent) was due principally to air infiltration, but to a considerable degree also to uneven firing producing high CO with low CO_2. Stopping up the air leaks and modifying the method of firing as illustrated by the record and using the CO_2 indicator as a guide, the fireman had no difficulty in maintaining an average of over 13 per cent of CO_2 with practically no CO. The temperatures of the escaping gases in this case being respectively 490 and 525, for Sec. 3

$$L = \left(0.24 + \frac{58.46}{8.75}\right) \times 490 = 3391 \text{ B.t.u.}$$

The gas produced with the heavy firing contained fully 0.3 per cent of CO, which represents a loss of

$$L_c = 10{,}150 \times \frac{P_c}{P - P_c} = 335 \text{ B.t.u.}$$

The heavy firing therefore produced a minimum heat loss of 3391 + 335 = 3726 B.t.u. per lb. of carbon burned, whereas in the improved firing, combustion being practically complete, this loss was:

$$L = \left(0.24 + \frac{58.46}{13}\right) \times 525 = 2488 \text{ B.t.u.}$$

hence a reduction of the heat loss up the chimney of

$$\frac{(3726 - 2488) \times 100}{3726} = 33.3 \text{ per cent.}$$

20 Contrary to what was seen in Secs. 1 and 2 of the chart, both the temperature of the escaping gases and the boiler draft are higher when the conditions had been changed so as to result in the higher percentage of CO_2. This may at first seem contradictory; but a little study reveals the fact that both the boiler draft and the temperature of the escaping gases were rendered abnormally low by the flow of air (counter draft) entering through the leaky setting. It is therefore necessary to make sure that the setting is made tight before these two factors can be relied upon as indices, respectively, of absorption efficiency and rate of combustion. Furthermore, a low

stack temperature cannot be relied on as an index to absorption efficiency unless the gases contain a high percentage of CO_2.

21 In Secs. 5, 6, 7 and 8 of the chart are recorded the averages four 24-hour tests of a large water-tube boiler burning bituminous coal fired by Roney stokers. The coal was burned at four different rates of combustion; viz., 16.7, 18.25, 25.3 and 30.8 lb. per sq. ft. of grate surface per hour. The CO_2 averaged 14.68, 13.05, 14.28 and 14.69 per cent; the boiler draft was 0.08, 0.12, 0.31 and 0.61 in. of water, and the temperature of the escaping gases averaged 483, 542, 662 and 636 deg. fahr., respectively. The efficiency attained in these tests was respectively 81.15, 77.45, 75.28 and 76.73 per cent.

RELIABILITY OF THE CHEMICAL METHOD OF CONTROL

22 Critics of the chemical method of control occasionally hold that CO_2 and boiler efficiency do not always bear a definite relation to one another, as, for example, in Sec. 5, 14.68 per cent CO_2 = 81.15 per cent efficiency, and in Sec. 8, 14.69 per cent CO_2 = 75.28 per cent efficiency; hence they argue that CO_2 cannot be a reliable guide to boiler operation.

23 Such critics overlook (or ignore) the fact that the boiler efficiency depends on two factors: combustion efficiency, represented by $0.24 + (58.46/P)$, and absorption efficiency, designated by $(T - t)$. Examining the results illustrated in Secs. 5 and 8 in the chart, it is seen that the temperature T in Secs. 8 is 153 deg. higher, which accounts for the 4.42 per cent lower efficiency with identical CO_2. Thus, while a high percentage of CO_2 may not always signify high boiler efficiency, a low percentage of CO_2 always means low efficiency. It goes without saying that the percentage of CO_2 must not be carried beyond the limit of practically complete combustion — this limit must be located by experiment. The maximum percentage of CO_2 that can be carried depends on:

a The kind of fuel
b The construction of the furnace
c The available draft
d The method of firing.

Having determined the maximum percentage of CO_2 that can be carried under given conditions, it must be maintained if maximum boiler efficiency is to result; but no fireman can maintain maximum CO_2 without a CO_2 indicator any more than he can maintain an even steam pressure without a steam gage.

24 The four tests referred to demonstrate that the percentage of CO_2 can be maintained at its maximum irrespective of the rate of driving without increasing the percentage of CO, provided there is ample space for combustion. *A large combustion chamber is a most vital factor in securing combustion efficiency.*

25 Sec. 9 of this chart illustrates the relation the three records will take to each other if the demand for steam suddenly increases and the draft is adjusted to increase the rate of combustion to meet this increased demand, but the stoker is not speeded up sufficiently to supply the coal required. The flue-gas temperature will at once go up in response to the increased rate of combustion. The CO_2 will soon begin to drop, and if there is no CO_2 indicator to show what is happening it will continue to drop until the fireman discovers that the grate is getting bare and the stoker speed must be increased. He does so, but gives it a little too much speed and the CO_2 goes above the safe limit. If he is a good fireman he will no doubt discover that also and finally get the right adjustment. Meanwhile considerable fuel has been wasted, first by excess air, and then by incomplete combustion. With a CO_2 indicator to guide him this would not have happened.

26 Sec. 10 illustrates how the boiler-draft and pyrometer records will at once reveal the sudden breaking down of a section of baffling. Sec. 11 shows how the average temperature and boiler draft would be affected if the baffling disintegrated gradually, and Sec. 12 indicates how the records would be likely to change if the boiler tubes were allowed to muck up gradually. These supposititious cases are given to show how the boiler draft and exit temperatures are affected by the same cause. Neither can be correctly interpreted without the other. Within practical limits of driving the maximum percentage of CO_2 can and should be maintained, whereas both the boiler draft and the exit temperature increase with the rate of driving. The exit gas temperatures vary from the normal from four distinct causes:

a Rate of driving
b Defective baffling
c Dirty heating surface
d Air infiltration.

The record of the boiler draft at once reveals the true cause; the pyrometer simply reveals the fact. Low exit gas temperature is generally taken to indicate absorption efficiency and the CO_2 record shows whether it is or not.

27 In the foregoing the author has endeavored to demonstrate

that the three records, viz., percentage of CO_2, temperature of the escaping gases, and the boiler draft, autographically recorded, preferably on the same chart, reveal in detail all the facts necessary for effective control of the boiler operation. They give a continuous up-to-the-minute history of the essential factors on which economic operation depends, and provide a ready means for interpreting the causes of irregularities, and for applying the proper remedy promptly and intelligently. The three records being on the same chart, they can be quickly integrated by a polar planimeter and averaged, and thus form the best basis for a bonus system.

28 Maximum efficiency cannot be expected, and it is doubtful whether it can be attained, unless the firemen have the means of knowing all the time how well they are succeeding in maintaining it. To this end it is necessary that they have in plain view, at or near the boiler front, a CO_2 indicator, a boiler-draft and also a furnace-draft gage. With these instruments to guide them the firemen can, after being properly instructed, always maintain the combustion conditions which will produce maximum efficiency under normal conditions, and do the best that can be done should the conditions pot under their control for any reason become abnormal.

29 In addition to the three recording instruments, an Orsat apparatus is also essential —

a For determining the maximum per cent of CO_2 that can be carried without danger of an appreciable loss because of incomplete combustion

b To diagnose the boilers for air infiltration at regular intervals, or in between, if deemed necessary, and

c To check up the CO_2 meters when their indications give cause for suspecting their accuracy.

An Orsat is by itself quite inadequate as a control for the firing operations of a boiler plant, even when supplemented by sampling tanks, which combination, although better than nothing, cannot be considered more than a makeshift.

INFORMATION MADE AVAILABLE BY APPLICATION OF AUTHOR'S FORMULÆ TO DATA DERIVED FROM AUTOGRAPHIC RECORDS OF CO_2

30 The method of control described is not only most direct, very simple and quite adequate, but it supplies the data necessary for deriving most desirable information, not otherwise available, in regard to the following details:

a Heat carried to waste by the dry gases
b Heat loss due to the CO contained in the gases
c Heat carried to waste by the steam resulting from the combustion of the available hydrogen in the flue
d Heat loss due to the water in the air
e Heat carried off by the water of hydration $(O - \frac{O}{8})$ contained in the fuel
f Heat carried to waste by the moisture in the fuel
g Percentage of excess air used
h Percentage of free oxygen contained in the gases
i Theoretical maximum percentage of CO_2 obtainable from the combustion of a fuel of given analysis
j Weight of dry gas produced per pound of carbon burned
k Volume of dry gas produced per pound of carbon burned
l An index to rate of combustion.

31 If the ultimate analysis of the fuel is known, and it always should be known, the values of all the above-mentioned items can be readily calculated by applying the very simple formulæ developed in the Appendix to the data derived from the autographic records of CO_2.

32 The usefulness and reliability of these formulæ are best shown by applying them to the data observed in a few authorative boiler tests and comparing the results.

33 Tests A and B, Table 1, were made on a large boiler of the Sterling type rated at 2400 hp., equipped with forced draft and Roney stokers; the fuel was Pittsburgh coal. Tests C and D were made on a 210-hp. Heine boiler, hand-fired. The fuel was No. 1 Arkansas briquets, in test C, and Illinois No. 3 coal in test D.

APPLICATION OF FORMULÆ DEVELOPED BY AUTHOR

34 Reducing the essential constituents of the coal to the carbon unit basis of 1 lb., gives

C	H	O	Ash	Moisture	B.t.u.
1.0	0.0683	0.1068	0.0925	0.023	17,984

The available hydrogen per pound of carbon is

$$0.0683 - \frac{0.1068}{8} = 0.055 \text{ lb.} = H_a$$

The water of hydration per pound of carbon is

$$0.1068 + \frac{0.1068}{8} = 0.12 \text{ lb.} = W_{hy}$$

35 Applying the formulæ developed in the Appendix to the da obtained in Test A, the heat carried up the chimney by the dry gase according to Formula [3], is

$$L_d = \left(0.24 + \frac{58.46}{P}\right) \times (T - t)$$

TABLE 1 DATA AND RESULTS OBTAINED IN FOUR AUTHORITATIVE BOILER TESTS

Test Data.	Test A	Test B	Test C	Test D
Analysis of Coal:				
Carbon, per cent	76.87	76.87	79.76	71.52
Hydrogen, per cent	5.31	5.31	3.91	4.53
Oxygen, per cent	8.32	8.32	2.70	8.18
Nitrogen, per cent	1.11	1.11	1.58	1.52
Sulphur, per cent	1.20	1.20	1.75	1.64
Ash, per cent	7.19	7.19	11.04	15.70
Moisture, per cent	1.80	1.80	0.94	8.51
B.t.u.	13,826	13,826	13,885	12,857
Analysis of Gas:				
CO_2, per cent	14.90	14.23	9.36	7.10
CO, per cent	0.23	0.36	0.00	0.04
O_2, per cent	3.40	4.30	10.57	13.40
Temperature of gas, T, deg. fahr.	483	670	624	535
Temperature of atmosphere, t, deg. fahr.	73	81	87	62
Total effective draft, in. of water	0.26	0.57	0.35	0.58
Furnace draft, in. of water	0.14	0.22	0.15	0.21
Boiler draft, in. of water	0.12	0.35	0.20	0.37
Humidity in air, per cent saturation	62.4	64.5	.....	.....
Carbon in ash, per cent	31.6	38.0	23.02	33.73
Duration of test, hours	24	30	10	10
Rated hp. of boilers	2400	2400	210	210
Test Results as Reported				
Efficiency, per cent	81.15	75.78	67.33	64.20
Heat loss up chimney, per cent	15.15	19.76	23.12	32.60
Heat loss in ash, per cent	2.29	2.13	.....	.....
Heat loss by radiation, etc., per cent	1.51	2.33	9.55	3.74
Total	100.00	100.00	100.00	100.00
Water evaporated per lb. of coal, lb.	9.95	9.01	7.9	6.2
Coal burned per hr. per sq. ft. of grate, lb.	14.81	25.97	18.74	21.23
Horsepower developed	2225	3606	206	201
Driving, per cent of rating	94	152	98.3	95.5

Substituting the values of P, T and t,

$$L_d = \left(0.24 + \frac{58.46}{14.91}\right) \times (483 - 73) = 1706 \text{ B.t.u.}$$

Also, the heat value of the CO contained in the gas, according to ormula [7], is

$$L_c = 10{,}150 \times \frac{P_c}{P + P_c}$$

Substituting the values of P_c and P,

$$L_c = 10{,}150 \times \frac{0.23}{14.9 + 0.23} = 10{,}150 \times 0.0151 = 153 \text{ B.t.u.}$$

36 From Formula [8] the heat carried off by the H_2O from the combustion of the available hydrogen, is

$$L_h = 8734\, H_a + 4.32\, H_a\, (T - t)$$

Substituting the values of H_a, T, and t,

$$L_h = 8734 \times 0.055 + (4.32 \times 0.055 \times 410) = 578 \text{ B.t.u.}$$

Also, the heat absorbed by the humidity in the air, according to Formula [9], is

$$L_v = A_v \left(\frac{117}{P} + 3.8\, H_a\right) \times (T - t)$$

37 The average temperature of the air during the test was 73 deg. and the average humidity 62.4 per cent saturation. At this temperature and saturation the water vapor carried into the furnace is 0.0106 lb. per lb. of air supplied = A_v. Substituting this value and the values of H_a, P and $(T - t)$ in Formula [9],

$$L_v = 0.0106 \left(\frac{117}{14.91} + 3.8 \times 0.055\right) \times 410 = 34 \text{ B.t.u.}$$

The heat carried by the water of hydration equals

$$L_w = W_{hy} \times (0.48\, T + 1080 - t)$$

Substituting the values of W_{hy}, T and t,

$$L_w = 0.12\, (0.48 \times 483 + 1080 - 73) = 149 \text{ B.t.u.}$$

Substituting the value of W_m for W_{hy}, the loss due to the moisture the coal is

$$L_w = 0.023\, (0.48 - T \times 483 + 1080 - 73) = 28 \text{ B.t.u.}$$

38 The foregoing comprise all the items of heat wasted up chimney with the exception of that contained in the hydrocarb if any, and in the soot and ash passing off with the gases, and be enumerated as follows:

HEAT-LOSS ITEMS UP THE CHIMNEY

	B.t.
a Heat carried to waste by the dry gases	17
b Heat value of CO	1
c I carried to waste by the H_2O from the combustion of the a le hydrogen	
the nidity in air	

	B.t.u.
f Heat carried to waste by the moisture in the coal	28
g Total heat in H_2O in gases	798
h Total heat in flue gas per lb. of carbon burned (items *a*, *b* and *g*)	2648

ence $\frac{2648 \times 100}{17984} = 14.72$ per cent of the heat of the coal remained ı the gases as they left the boiler.

39 The ash contained 31.6 per cent of carbon and since the coal ontained 0.0925 lb. of ash per lb. of carbon, the loss due to the heat alue of the combustible in the ash is

$$0.316 \times 0.0925 \times 14{,}600 = 427 \text{ B.t.u.}$$

hich represents

$$\frac{427 \times 100}{17{,}984} = 2.38 \text{ per cent of the heat in the coal.}$$

40 The total heat loss accounted for by the preceding calculaons is therefore

	Per Cent.
Heat absorbed by boiler	81.10
Heat loss up the chimney	14.72
Heat loss through the grate	2.38
Heat loss from radiation, etc	1.80
Total	100.00

41 The heat-loss items in Test A were reported as follows:

	Per Cent
Moisture in coal	0.16
Hydrogen in coal	4.29
Heat to chimney	9.11
Moisture in air	0.20
Carbon monoxide	1.29
Carbon in ash	2.29
Total losses accounted for	17.34
Absorbed by boiler	81.15
Radiation, etc	1.51
Total	100.00

42 Applying the same formulæ to the observed data of Tests B, and D, the results given in Table 2 are obtained.

43 Combustion efficiency in the operation of a boiler means not nly that all the combustible in the fuel must be completely oxidized, ut that it must be oxidized in a manner that the maximum amount f the heat liberated becomes available to the boiler. Theoretically

all the heat liberated by combustion is available to the boiler except that contained in the gases below the temperature of the water in the boiler and the latent heat of the H_2O contained in the gases.

TABLE 2 RESULTS OF APPLICATION OF FORMULÆ TO DATA OF TESTS B, C AND D

	Test B	Test C	Test D
a Heat carried to waste by dry gases, B.t.u.	2560	3480	4553
b Heat value of CO contained in gases, B.t.u.	251	0	57
c Heat in H_2O from combustion of available hydrogen, B.t.u.	610	497	549
d Heat loss due to humidity in air, B.t.u.	72	.....	.....
e Heat carried to waste by water of hydration, B.t.u.	153	36	164
f Heat carried to waste by moisture in coal, B.t.u.	29	15	154
g Total heat in H_2O in gas, B.t.u.	864	548	267
k Total heat in flue gas per lb. of carbon burned, B.t.u.	3675	4028	5777
Heat of coal remaining in gases leaving boilers, per cent	20.43	23.17	32.14
Heat loss due to combustible in ash { B.t.u.	416	429	867
Heat loss due to combustible in ash { per cent of coal	2.31	2.47	4.82
Total Heat Loss:			
Heat absorbed by boiler, per cent	75.78	65.39	60.22
Heat loss up the chimney, per cent	20.43	23.17	32.14
Heat loss through grates, per cent	2.31	2.47	4.82
Heat loss from radiation, etc., per cent	1.48	8.97	2.65
Total	100.00	100.00	100.00
Losses in Test Report:			
Moisture in coal, per cent	0.17	.....	.....
Hydrogen in coal, per cent	4.49	.....	.....
Heat to chimney, per cent	12.79	.....	.....
Moisture in air, per cent	0.36	.....	.....
Carbon monoxide, per cent	1.95	.....	.....
Carbon in ash, per cent	2.13	.....	.....
Total loss accounted for, per cent	21.89	.....	.....
Heat absorbed by boiler, per cent	75.78	.....	.....
Heat lost in radiation, etc., per cent	2.33	.....	.....
Total	100.00	.....	.....
Heat Balance in Test Report:		Per cent	Per cent
Heat absorbed by boiler (= evaporation from and at 212 deg. per lb. of combustible)	.....	62.33	64.20
Loss due to moisture in coal (= per cent of moisture referred to combustible)	.....	0.69	0.96
Loss due to moisture formed by burning of hydrogen (= per cent of hydrogen referred to combustible)	.....	3.23	4.13
Loss due to heat carried away by dry chimney gases (= weight of gas per lb. of combustible)	.....	19.75	26.69
Loss due to unconsumed hydrogen, heating of moisture and unaccounted for	.....	9.55	3.74
Loss due to incomplete combustion of carbon	.....	.....	0.32
Total	.....	100.00	100.00

Hence combustion efficiency so far as it is under the control of the fireman $= \dfrac{\text{Heat availably liberated}}{\text{Available heat in fuel}}$.

44 Analyzing the results of these heat-loss calculations it is found that in Test A, $1706 \times 100/2648 = 64.12$ per cent of the heat up the chimney is carried by the dry gases, and that the heat value of the CO amounts to $153 \times 100/2648 = 5.78$ per cent. The remainder, or 30.1 per cent, is carried off by the H_2O from coal and air.

45 Since the gases cannot be cooled below the temperature of the water in the boiler, it is evident that only the heat contained in the gases above that temperature is under control of the boiler operation.

46 Applying Formula [**12**][1] it is found that the theoretical maximum percentage of CO_2 obtainable from the coal used in Test A is

$$P_m = \frac{21}{1 + (2.38 \times 0.055)} = 18.57.$$

TABLE 3 ANALYSIS OF HEAT ESCAPING UP THE CHIMNEY

	Test A	Test B	Test C	Test D
(1) Per cent of heat up the chimney contained in the dry gas	65.20	69.66	86.40	84.02
(2) Per cent of heat escaping up the chimney represented by CO	5.80	6.83	0.00	0.98
(3) Per cent of heat escaping up the chimney due to H_2O	29.00	23.51	13.60	15.00
(4) Per cent of heat controllable in item (1)	27.00	48.43	69.40	78.26
(5) Per cent of heat controllable in item (2)	100.00	100.00	100.00	100.00
(6) Per cent of heat controllable in item (3)	8.50	7.80	11.20	7.50
(7) Per cent of the controllable heat residing in the dry gas	85.20	94.90	97.40	98.70
(8) Per cent of excess air	23.00	29.00	97.00	160.00
(9) Per cent of free oxygen in gas	4.16	4.83	10.57	13.10

47 The temperature of the water in the boiler corresponding to the average steam pressure carried during Test A was 384.6 deg. fahr. Applying Formula [**4**], the uncontrollable heat in the dry gases per pound of carbon burned is found to be

$$L_d = 0.24 + \frac{58.46}{18.57} \times 384.6 = 1246 \text{ B.t.u.}$$

or

$$\frac{(1706 - 1246) \times 100}{1706} = 27 \text{ per cent}$$

hence only 27 per cent of the heat in the dry gases in this test was controllable.

[1] See Par. 74, in Appendix.

48 The loss due to CO is independent of the stack temperature, and since the percentage of CO in the gas can be reduced to zero, the heat loss due to its presence is 100 per cent controllable.

49 Since the heat loss due to the H_2O in the gases is independent of the CO_2, only that portion is controllable which is affected by the temperature of the flue gas above that of the water in the boiler.

50 The latent heat of evaporation is not controllable, hence the terms in the formula representing it must also be eliminated. Thus, applying the modified formula to the observed data we have for the controllable heat in H_2O:

$$\left[4.32 \times 0.055 + 0.0106 \times \left(\frac{117}{14.9} + 3.84 \times 0.055\right)\right] \times (583 - 385) + 0.48 \times (583 - 385) \times 0.143 = 67.53 \text{ B.t.u.}$$

Since the total heat carried to waste by the H_2O in the gas is 798 B.t.u., it is seen that only $\frac{67.53 \times 100}{798} = 8.5$ per cent of it is controllable.

51 Of the heat in the dry gas (1706 − 1246 =) 460 B.t.u. were controllable, hence the total controllable heat escaping amounts to 460 + 67.5 = 527.5 B.t.u., and of this $\frac{460 \times 100}{527.5} = 87.2$ per cent resides in the dry gases.

52 Table 3 gives the results of the foregoing calculations for the four tests under consideration. Item (1) shows what percentage of the heat wasted up the chimney is contained in the dry gas that can be controlled to a greater or lesser degree by improving operating conditions. Item (7) shows what percentage of the controllable heat resides in the dry gases. All of which emphasizes the importance of the CO_2 and temperature records, as controlling factors in boiler operations.

53 The fireman must drive his boilers in accordance with the demand for steam. He has no control over the condition of the heating surface of his boilers. And since the temperature of the escaping gases depends primarily on one or both of these conditions it is not fair to him to judge his proficiency by heat wasted up the chimney, and much less fair is it to judge him on the basis of pounds of water evaporated per pound of coal burned. In Test A, for example, there was 10 per cent more water evaporated than in Test B, while the difference in furnace efficiency based on heat available was only 2.4 per cent, as demonstrated above.

54 The proper basis upon which to judge the proficiency of a fireman is the factor $0.24 + \frac{58.46}{P}$ after the maximum percentage of CO_2 (P) with practically complete combustion has been established for the prevailing conditions at any given plant.

55 Within proper limits of CO_2 there exists no relation between the percentages of CO_2 and CO. Test B, for example, shows 0.7 per cent less CO_2 and 0.13 per cent more CO than test A. Furthermore, it must be borne in mind that the loss due to the same percentage of CO diminishes directly as the percentage of CO_2 increases, as is shown by the factor $\frac{P_c}{P + P_c}$. It is a matter of easy calculation to determine where the loss due to a definite increase in CO will overbalance the gain from an increase in CO_2 making the CO probable.

56 Assuming, for example, that under the furnace and fuel conditions existing when Tests A and B were made, 14 per cent was the safe limit for CO_2 for complete combustion, how much CO will it take to overbalance the benefit of raising the CO_2 to 16 per cent, assuming $T - t = 450$ deg.?

57 Applying Formula [4], it is found that there is a gain of $\left[\left(0.24 + \frac{58.46}{14}\right) - \left(0.24 + \frac{58.46}{16}\right)\right] \times 450 = 234$ B.t.u., and Formula [7] shows that this gain would be overbalanced by $10{,}150 \times \frac{P_c}{16 + P_c} = 234$, from which $P_c = 0.38$ per cent. Therefore, if the increase of CO_2 from 14 to 16 per cent cannot be accomplished without at the same time increasing the percentage of CO by 0.38 per cent, there is no gain in heat to the boiler.

58 But since there is no definite relation between the percentage of CO_2 and CO, it follows that within proper limits, depending on the construction of furnace, method of stoking, kind of fuel, air control, etc., maximum CO_2 can be attained without appreciable amounts of CO if the fireman exercises proper care and judgment. What these limits are must be ascertained by experiment for each plant, and if the construction of furnace, and method of stoking vary appreciably it may be necessary to determine the maximum economic percentage of CO_2 for each boiler. But such determination is of small avail unless the firemen are properly instructed how to get maximum CO_2 with a negligible percentage of CO and have continuously brought to their attention the percentage of CO_2 they are getting.

APPENDIX

DEVELOPMENT OF FORMULÆ FOR CALCULATING HEAT LOSSES IN CHIMNEY GASES

59 The object in developing the following formulæ is threefold: (1) To furnish a ready means for calculating the heat losses up the chimney; (2) to make these calculations so simple that a knowledge of atomic and molecular weights, specific heats, etc., is not necessary, so that operating engineers not familiar with chemistry can quickly and easily ascertain the heat losses in so far as they have the necessary data; (3) to bring out the heat losses in detail, showing the factors on which they depend, and separating the losses over which the fireman has no control from those over which he has. All of which is for the purpose of stimulating or intensifying the interest of the operating engineer in the operation of his boilers, and enabling him to get after defects with a confidence born of knowledge, based on observed facts intelligently interpreted, and thus to maintain maximum boiler efficiency.

60 The formulæ developed in the following paragraphs are based on a weight of fuel containing 1 lb. of carbon instead of on 1 lb. of fuel or combustible. To change the analysis of any given fuel to the carbon unit basis, divide the weight of all the constituents by the weight of carbon per pound of fuel. Thus, if the principal constituents in a given coal are: C, 71.52 per cent; H, 4.53 per cent; O, 8.18 per cent; S, 1.64 per cent, and ash, 12.61 per cent, every pound of the coal contains 0.7152 lb. of carbon, 0.0453 lb. of hydrogen, 0.0818 lb. of oxygen, 0.0164 lb. of sulphur and 0.1261 lb. of ash, and dividing the weight of each constituent by the weight of carbon, gives:

$$C = 1, \quad H = 0.0633, \quad O = 0.1144, \quad S = 0.023, \quad Ash = 0.172.$$

The heat value of dry coal of this composition is 12,857 B.t.u. per lb. of coal, and on the carbon unit basis it would be 12.857/0.7152 = 17,978 B.t.u.

61 In developing the formulæ the following symbols are used:

O = weight of oxygen per lb. of carbon in the fuel
H_t = weight of hydrogen per lb. of carbon in the fuel
$H_a = H_t - \frac{O}{8}$ = weight of available hydrogen per lb. of carbon in the fuel
A_c = weight of air required to burn 1 lb. of carbon
A_h = weight of air required to burn 1 lb. of hydrogen
A_t = total weight of air supplied
A_e = weight of excess air supplied
N_h = weight of nitrogen in weight of air required to burn 1 lb. of hydrogen
A_v = weight of water vapor per lb. of air supplied per lb. of carbon burned
G_w = weight of dry gas per lb. of carbon burned
G_v = volume of dry gas at 62 deg. fahr. per lb. of carbon burned
W_m = weight of moisture in fuel per lb. of carbon
$W_{hy} = O - \frac{O}{8}$ = weight of water of hydration in fuel per lb. of carbon
P = per cent of CO_2 in flue gas
P_c = per cent of CO in flue gas
P_e = per cent of excess air in flue gas
P_o = per cent of free oxygen in flue gas

P_m = maximum theoretical per cent of CO_2 obtainable from any given fuel
S = 0.24 = specific heat of dry gases
S_w = 0.48 = specific heat of steam
L_a = 970.4 = latent heat in 1 lb. of steam
T = temperature of gases on leaving the boilers, deg. fahr.
t = temperature of air supplied for combustion, deg. fahr.
L_d = B.t.u. carried off by dry gas per lb. of carbon burned
L_c = heat value of CO contained in gas per lb. of carbon burned
L_h = B.t.u. carried off by H_2O produced by the combustion of the available hydrogen per lb. of carbon burned
L_v = B.t.u. carried off by water vapor in the air supplied to burn 1 lb. of carbon
L_{hy} = B.t.u. absorbed and carried off by water of hydration per lb. of carbon burned
L_m = B.t.u. absorbed and carried off by moisture per lb. of carbon burned

Air contains	Per cent by weight	Per cent by volume
Oxygen	23	21
Nitrogen	77	79

One cubic foot of air at 62 deg. fahr. weighs 0.0761 lb.
One cubic foot of nitrogen at 62 deg. fahr. weighs 0.0742 lb.

62 *Complete Combustion of Pure Carbon.* — According to Avogadro's law all gaseous molecules occupy the same space, from which it follows that the volume of $O_2 = CO_2$, and hence when carbon is completely burned with the theoretical amount of air required, the products of combustion must contain 21 per cent of CO_2.

63 Since the atomic weights of C and O are respectively 12 and 16, it takes $2 \times 16/12 = 2.67$ lb. of oxygen to burn one pound of carbon; and since every pound of oxygen is accompanied by $77/23 = 3.348$ lb. of nitrogen, the weight of air required to burn 1 lb. of carbon $= (2.67 \times 3.348) + 2.67 = 11.6$ lb., which has a volume of $11.6/0.0761 = 153$ cu. ft. at 62 deg. fahr.

64 Therefore, when carbon is burned to CO_2 with the theoretical amount of air the folowing equations are true:

$$P = \frac{152 \times 21}{152} = \frac{A_c \times 21}{A_c} = \frac{11.6 \times 21}{11.6} = \frac{243.6}{21} = 21$$

When carbon is burned with an excess weight of air, $A_e = A_c/0.0761$ by volume, in which case

$$P = \frac{152 \times 21}{152 + \text{volume of excess air}} = \frac{152 \times 21}{152 \times \dfrac{A_e}{0.0761}}$$

$$= \frac{11.6 \times 21}{11.6 + A_e} = \frac{A_e \times 21}{A_c + A_e},$$

From which

$$A_e = \frac{A_c \times 21}{P} - A_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [1]$$

65 The weight in lb. of the products of 1 lb. of carbon is equal to 1 + the weight of air supplied, hence,

$$G_w = 1 + A_t, \quad \text{and} \quad A_t = A_c + A_e$$

Substituting the value of A_e in [1],

$$A_t = \frac{A_c \times 21}{P} = \frac{11.6 \times 21}{P} = \frac{243.6}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

$$L_d = (1 + A_t)\, S \times (T - t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

Substituting the value of A_t and S in [3],

$$L_d = \left(0.24 + \frac{58.46}{P}\right) \times (T - t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

66 *Heat Carried Off by the Dry Gases When the Fuel Contains Hydrogen.* — The combustion of 1 lb. of hydrogen requires 8 lb. of oxygen, which is accompanied by $8 \times 77/23 = 26.8$ lb. of nitrogen. Hence $N_h = 26.8$ lb. and $A_e = 26.8 + 8 = 34.8$ lb. When fuel containing hydrogen is burned with an excess of air

$$P = \frac{A_c \times 21}{A_c + N_h \times H_a + A_e},$$

from which

$$A_e = \frac{A_c \times 21}{P} - (A_c + N_h \times H_a) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

In this case

$$L_d = (1 + A_c + N_h \times H_a + A_e)\, S \times (T - t)$$

Substituting the values of S and of A_e from [5],

$$L_d = \left(1 + \frac{58 + .46}{P}\right) \times (T - t) \quad . \quad . \quad . \quad . \quad . \quad . \quad [6]$$

which is identical with equation (4) as it should be.

67 *Heat Value of the CO Contained in the Escaping Gases.* — The weight of carbon in a molecule of CO is the same as that in a molecule of CO_2, hence it follows from Avogadro's law that the weight of carbon burned to CO is to the weight burned to CO_2 as the percentage of CO is to the percentage of CO_2 contained in the escaping gases.

68 Thus, letting X = weight of carbon burned to CO

$$\frac{X}{1 - X} = \frac{P_c}{P}, \text{ from which } X = \frac{P_c}{P + P_c}$$

and since 1 lb. of carbon burned from CO to CO_2 develops 10,150 B.t.u.,

$$L_c = 10{,}150 \times \frac{P_c}{P + P_c}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [7]$$

69 *Heat Carried Off by the H_2O from the Combustion of H_a.* —

$$L_h = 9\, L_a \times H_a + 9\, H_a \times S_w \times (T - t).$$

Substituting the values of L_a and S_w,

$$L_h = (8734 \times H_a + (4.3 \times H_a)\,(T - t). \quad . \quad . \quad . \quad . \quad . \quad [8]$$

70 *Heat Loss Due to Water Vapor in Air.* — Atmospheric humidity exerts a chilling effect on the fire because of its high specific heat and because at least part of it will be decomposed; but since under normal conditions the hydrogen which is set free by decomposition will reunite with oxygen in the combustion chamber and will evolve as much heat as was absorbed in setting it free, there

results no heat loss from this double reaction. It will be necessary, therefore, to consider only the sensible heat carried off by H_2O entering with the air, hence

$$L_v = A_v \times (A_c + A_h \times H_a + A_e)\, S_w \times (T - t).$$

Substituting the value of S_w and of A_e from [5],

$$L_v = A_v \left(\frac{117}{P} + 3.8\, H_a\right) \times (T - t). \quad . \quad . \quad . \quad . \quad . \quad . \quad [9]$$

71 *Heat Loss Due to Water in Fuel.* — The water in solid fuels exists in two forms: water of hydration, W_{hy}, and moisture, W_m. This water must first be raised from the temperature t of the firing room to 212 deg., then evaporated and passed off with and at the temperature of the escaping gases; therefore,

$$L_w = (W_m + W_{hy}) \times [212 - t + 970.4 + (T - 212)\, S_w].$$

Substituting the value of S_w,

$$L_w = (W_m + W_{hy}) \times (0.48\, T + 1080 - t).$$

72 *Percentage of Excess Air.* —

$$P_e = \frac{\text{Excess air} \times 100}{\text{Theoretical air required}} = \frac{A_e \times 100}{A_c + A_h \times H_a}$$

Expressed in terms of volume,

$$P_e = \frac{\left(\dfrac{152 \times 21}{P} - (152 + 361\, H_a)\right) \times 100}{152 + 457\, H_a}$$

which reduces to

$$P_e = \frac{2100}{P\,(1 + 3\, H_a)} - \frac{100\,(1 + 2.38\, H_a)}{1 + 3\, H_a}. \quad . \quad . \quad . \quad . \quad . \quad [10]$$

73 *Percentage of Free Oxygen in Gases.* — The percentage of free oxygen in the gas equals the excess air times the percentage of oxygen in the air divided by the total volume of the gas; hence,

$$P_o = \frac{A_e \times 21}{A_c + N_h \times H_a + A_e}.$$

Substituting the volume values of A_e, A_c, and N_h in this equation and reducing,

$$P_o = 21 - (1 + 2.38\, H_a) \times P. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [11]$$

74 *Theoretical Maximum Percentage of CO_2.* — The theoretical maximum percentage of CO_2 obtainable from a fuel of a given analysis equals the theoretical volume of air required to burn 1 lb. of carbon times the percentage of oxygen in the air, divided by the theoretical volume of dry gas produced in burning a weight of fuel containing 1 lb. of carbon.

$$P_m = \frac{A_c \times 21}{A_c + N_h \times H_a} = \frac{152 \times 21}{152 + 361\, H_a} = \frac{21}{1 + 2.38\, H_a}. \quad . \quad . \quad . \quad [12]$$

75 From [2] the weight of air required to burn one pound of carbon is $A_t = 243.6/P$, hence the weight of gas is

$$G_v = 1 + \frac{243.6}{P} \text{ lb.}$$

This is also the weight of the dry gas when the fuel burned contains hydrogen as is seen from the development of Formula [6].

76 The volume of the dry gas per lb. of carbon burned at 62 deg. fahr. is

$$G_v = \frac{152 \times 21}{P} = \frac{3192}{P} \text{ cu. ft.}$$

77 That the formulæ herewith developed give correct results has been demonstrated by applying them to authoritative and carefully executed tests. Thus if we know the analysis of the fuel and the percentages of CO_2 and CO in the flue gas and its temperature, we can not only readily make a heat balance, but can determine all other important and useful factors without the knowledge of molecular weights, specific heats, etc., and without the elaborate calculations usually involved.

DISCUSSION

W. N. Polokov said that the paper laid stress on the details of analyzing boiler performance, but in his opinion the attention to the performance itself was *the* important thing. He exhibited three charts on the screen in which the percentage of coal used productively

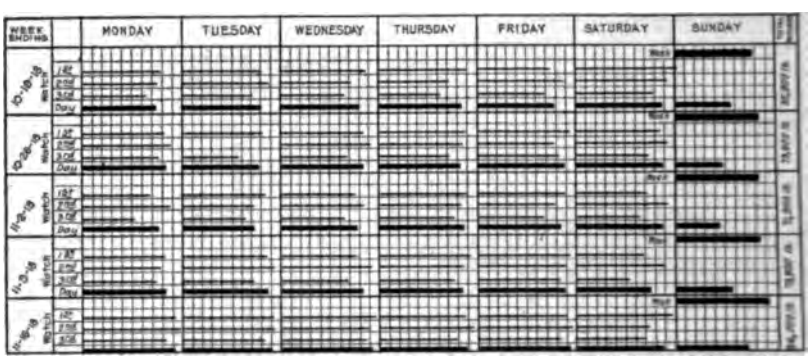


Fig. 2 Chart for Recording Coal Consumption in a Power Plant

(Black lines indicate percentage of coal used productively. Red extensions referred to in text not shown.)

in a plant was indicated by a black line, the line being continued in red to represent the percentage used wastefully. By determining what the evaporation should be in a given plant and then offering an incentive to the firemen to obtain such a result the red portion of the lines on the chart would gradually be replaced by black, indicating a corresponding reduction in the coal wastefully consumed. One of these charts is reproduced in Fig. 2; the continuations of lines in red, however, are not shown. Mr. Polakov also had projected on the screen several views of installations of boiler- and combustion-control instrument boards which he had devised.

D. S. JACOBUS. A greater number and a better quality of instruments are being provided than formerly to guide the operators in securing good results from boiler plants. The results secured under test conditions are usually regarded as being considerably above what can be obtained in regular operation, and there is every reason why there should be a considerable difference if the operating crew is not given the proper instruments to work with.

Experts will make tests at a plant, employing any number of high-grade indicating and recording instruments and obtain a high efficiency, and will say to the operating crew, "That is the way to do it." They then will take away all of the instruments and make the mistake of expecting the crew to obtain good results. This method is bound to lead to disappointment, as the regular crew can secure no better results without the proper instruments to guide them than could the experts if they attempted to operate the plant without the instruments.

We are now installing boiler plants that would not have been considered, say, ten years ago on account of the complication required to secure additional efficiency. Good results have been obtained at these plants through using the proper number and right type of instruments and through a proper training of the operators. It does not require a technically trained man to use instruments of this sort to advantage and it has been found that the very same men that have operated older boiler plants where simplicity was sought in every detail have made a success in operating the more complex plants and have become enthusiasts in obtaining the very best results.

The author's method of estimating the heat loss, or any other method based on the flue-gas analyses and the thoroughness of fuel combustion, does not make it possible to separate the efficiency of the furnace from that of the boiler, or to include all possible losses, as there is a feature of the combustion entirely apart from what is given by such data which influences the combined efficiency of the boiler and furnace. For this reason one cannot base a guarantee for the combined boiler and furnace efficiency exclusively on data of this sort. This is on account of the fact that delayed combustion between the tubes of the boiler has a great influence on the flue-gas temperature. As good flue-gas analyses may be obtained where there is delayed combustion as where all of the combustion is secured within the boiler furnace, but it can readily be seen that unless all of the combustible elements are burned within the furnace there will be a falling off in the efficiency. This fact is being appreciated more

and more and the general practice is to employ larger furnaces than formerly. In some instances we are installing furnaces which are three times as large for a given class of work as in the past and are obtaining additional efficiency thereby.

VICTOR J. AZBE said that practically all engineers realized the importance of large combustion chambers and that boilers with a space of 7 ft. between the grate and the lower row of tubes were now being installed. If boilers were studied from the standpoint of gas velocities and circulation was so maintained that all the benefit possible was obtained from the combustion space, much higher boiler efficiencies would result.

THOMAS J. GANNON (written). During the war the destructive work of the submarine brought up for solution the dual problem of smokeless combustion of bituminous coal in marine boilers of cargo-carrying vessels and of steaming these boilers continuously at their maximum capacity. The solution of the problem was conducted under the immediate direction of Mr. A. M. Hunt, member of the Ship Protection Committee of the United States Shipping Board, and the writer had immediate charge of the development work.

The solution sought would first reduce the radius of visibility of the vessel from approximately 25 miles to, say, 10 to 12 miles, thus increasing the effectiveness of the protective torpedo-boat destroyers manyfold, and secondly, would increase the average speed of the cargo carriers in convoy from approximately 50 per cent of rated speed (speed of convoy governed by speed of slowest boat) to full rated speed, thereby doubling the cargo-carrying effect of the vessels.

In the method developed the coal as received and without drying was first crushed so that no particle exceeded $\frac{1}{4}$ in. in diameter, and was then projected into the furnace by a jet of air compressed to a pressure of 3 to 5 lb. gage.

The granulated fuel was lifted into the projecting device by the vacuum produced by the jet of expanding air, which delivered it to the fuel-spreading nozzles which sprayed it on the fuel bed. The fuel bed was carried on the ordinary flat grates in the corrugated furnaces of the boiler. The transporting air was approximately equal in amount to that required for the complete combustion of the volatile matter in the coal. At the high temperature produced in the combustion chamber all the volatile matter was evolved and

burned during the time that it took the fuel to travel as a falling body from the feeding nozzle to the fuel bed, where it arrived as a very light, porous coke. This coke was burned readily by air under a very slight forced draft, at the exact rate at which it was deposited, so that the fuel bed was of constant thickness.

The combustion therefore involved: (1) the evolution and complete combustion in suspension of the volatile combustible matter; (2) the complete combustion in the same manner of the dust or powdered coal, and (3) the combustion on the flat grate of the porous coke.

Briefly the results obtained were as follows:

a The fuel fed into furnace continuously at the rate necessary to develop full boiler horsepower

b High furnace temperature, producing quick evolution of volatile matter from the coal

c Complete combustion of volatile matter by transporting air at the high temperature present in the furnace

d The apparent absence of clinker

e The entire absence of smoke

f The operating of boiler above rated capacity.

From the foregoing it is apparent that the boiler operation was easily controlled mechanically, as the coal fed per unit of time and the air required for the combustion of its volatile matter could be measured direct, and as a fuel bed of pure coke of constant thickness was easily maintained by means of the ordinary draft gage. The use of a steam or feedwater meter might have added further to the control.

Exact quantitative results on the installation were not attained, as the signing of the armistice brought all development work of a protection character to an end, and further progress on this method of burning coal will depend on private effort.

THE AUTHOR. Mr. Polakov exhibited a number of slides which showed all the instruments he deems necessary and adequate to get the results desired. But before every instrument board the author noticed a chair, which means that a permanent attendant is necessary to watch the instruments, make the necessary gas analyses and coördinate and interpret the results.

That will do in large plants that can afford an expert attendant, but it is not suited for a plant of moderate size. The author has no criticism to make of Mr. Polakov's system of control, but believes

that the same end can be reached in a more direct, simpler and cheaper way. He holds that the three autographic records as illustrated in his paper give adequate information for controlling economic boiler operation; and furthermore, that these autographic records will serve as a true basis for an equitable bonus system, as he will endeavor to show in a future contribution on the subject to the Society.

No. 1662

DISCUSSION OF CERTAIN PROBLEMS IN REGARD TO MARINE DIESEL OIL ENGINES

By John W. Anderson, Groton, Conn.
Junior Member of the Society

The methods of reversing as originally adopted in the German design for two-cycle engines and the method developed by an American firm for four-cycle engines, are discussed. A modification introduced in a two-cycle slow-speed engine used in a submarine tender proved satisfactory.

Diesel engines are usually started by means of compressed air; in small marine engines, a clutch between the engine and the propeller permits the independent starting of the engine. In all cases a smooth start is secured by bringing first the temperature in the cylinders to approximately the same value it has under working conditions. Regular turning moment and definite ignitions in the cylinders make possible the successful operation of a Diesel engine at slow speed. In the large sizes a smooth running at low speeds with light loads is obtained by a mechanism controlling the lift and timing of the spray valve.

While lubrication by gravity is used successfully in large open-frame slow-speed engines, the increasing adoption of forced lubrication in engines of all types and sizes is an evidence of the superior advantages of the latter system.

The satisfactory results given by the 2500-hp. six-cylinder two-cycle Diesel engines of the U. S. S. "Maumee" point out that all ocean-going cargo vessels can be equipped with Diesel engines.

Several features of the fuel system, the arrangement of the exhaust piping, the varieties of muffler, and the systems of cooling the various parts of Diesel engines, are considered from the point of view of the author's experience.

THE method of reversing used on the two-cycle engines is based on the fact that, in these engines, the spray and scavenger valves can be set right for running in the reverse direction by shifting the cams through a common angle. One camshaft running along the tops of the working cylinders operates all the valves; there is one cam for each spray and scavenger valve and the camshaft is shifted for reversing through an angle of 30 deg. The camshaft is shifted automatically by a slip coupling, Fig. 1, having a 30-deg.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

angle between the jaws, so that when the engine starts in the reverse direction, the crankshaft revolves 30 deg. before the camshaft starts; that is, when the timing becomes right for the new direction of rotation. The air starting valves are operated by two separate cams, one for ahead and one for astern, and the direction of rotation of the engine is determined by bringing into action the proper cam, which in turn times the starting valve.

2 This automatic reversing mechanism fails to work satisfactorily when the engine is operated at low speed, because then the engine does not turn exactly uniformly; and since the slip clutch is of the friction type with jaws to limit the extreme travel to 30 deg., and the camshaft and its parts have inertia of their own, this slip clutch fails to hold the camshaft in exact relation to the crankshaft. This upsets the timing of the valves, which in the case of the spray valve is important.

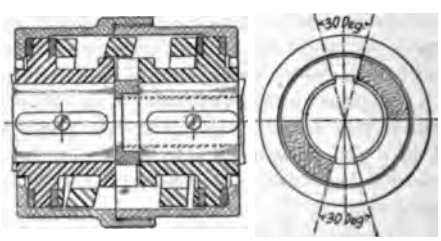


FIG. 1 SLIP COUPLING FOR AUTOMATIC SHIFT OF CAMSHAFT

3 In the 1000-hp. engine installed in the single-screw submarine tender *Fulton* the shifting of the camshaft was made definite and positive by substituting, in place of the slip clutch, a sliding sleeve operated by a pneumatic cylinder under the control of the handling gear shown in Fig. 2. The vertical shaft, which drives the camshaft from the crankshaft is cut and the sliding sleeve connects the two parts; it slides on one of them on straight keys parallel to the longitudinal axis of the shaft, and on the other on spiral grooves, so that when the sleeve is moved along the axis of the vertical shaft the camshaft is twisted relatively to the crankshaft through the same angle of shifting used in the original design, namely, 30 deg.

4 To make the action still more positive, there is an automatic locking device on the pneumatic cylinder. It consists of a bar with two holes, connected to the lever operating the sleeve; corresponding to these holes there are two locking pins, one for each end of the pneumatic cylinder. The parts are so arranged that when the sleeve

is in either extreme position, one of the locking pins fits into the proper hole in the locking bar and the parts are held securely in place.

5 When it is desired to reverse the engine, air is admitted by the handling gear to a piston on the locking pin holding the bar. This air pressure pulls the locking pin out, and when the pin is clear of the bar a port is uncovered leading to the pneumatic cylinder. The air pressure acting on the piston in the cylinder moves it to the other extreme position, setting the camshaft right for running in the opposite direction, and just as it reaches the extreme position it uncovers a port in the cylinder, admitting the air to the air starting valves on the working cylinders. Of course it is understood that when this gear reaches its new extreme position, the locking pin at that end of the cylinder registers with the hole in

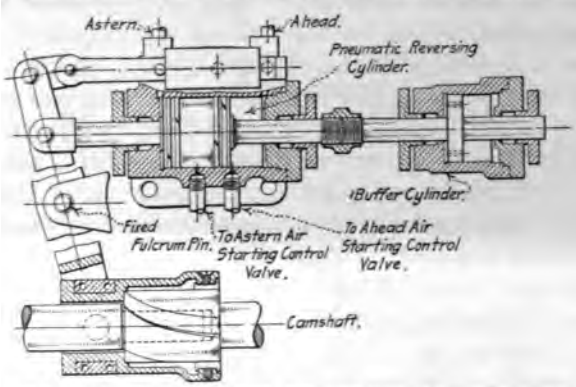


FIG. 2 DETAILS OF REVERSING MECHANISM OF SUBMARINE TENDER "FULTON"

the bar and again locks the mechanism. The action is very simple and thoroughly foolproof and positive. This engine has been in service for some time now, and the reversing gear has amply lived up to expectations.

6 A similar method of reversing has been developed by the American company for use on four-cycle engines (Fig. 3), but unfortunately in this case it is necessary to have a separate camshaft for each kind of valve because of the different angles through which it is necessary to shift the cams in order to bring the timing right for the new direction of running. The engines are fitted with three camshafts, one for the spray valves, one for the inlet valves, and one for the exhaust valves. The air starting valves are operated by a single cam which is shifted by a separate mechanism to bring its timing right The operation is pneumatic and the valves are controlled by plungers

arranged radially around the single cam, in accordance with the proper sequence of cranks. All of the camshafts are shifted by means of a single pneumatic cylinder operating sliding sleeves similar to the one just described, except for the addition of a set of jaws on the camshaft which register with jaws in the sliding sleeve in its extreme positions and take the driving effort. The work of the spiral grooves is thus confined exclusively to shifting the camshaft. As in the two-cycle engines, only a single cam is provided for each valve. This method of reversing has been applied to several engines and acts as satisfactorily in the case of the four-cycle engines as for the two-cycle.

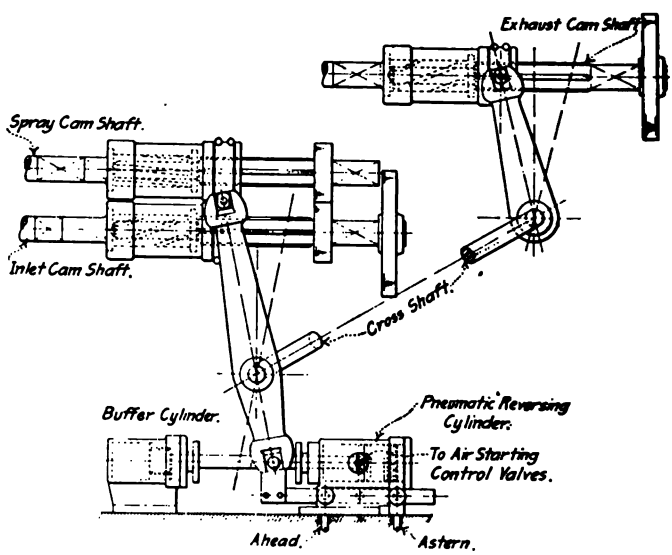


FIG. 3 FOUR-CYCLE-ENGINE REVERSING MECHANISM

7 The method of starting a Diesel engine which is almost universally used is by means of compressed air, and in most cases the air enters the working cylinders. The objection often raised against this practice is that rapid temperature changes are produced in the cylinders by the chilling effect of the expanding starting air alternating with the heat due to compression and then, after a few strokes, the heat due to combustion. However, this method gives satisfactory service and no ill effects are known to result in the cylinder from its use.

8 In starting, the air is ordinarily turned on for only a few seconds, and in a few seconds more the engine can be brought right

up to full power if desired. In fact, with a perfectly cold engine the operation will be a great deal smoother under a moderate load immediately after starting than it will be at a very light load. This applies particularly at low speeds. For stationary engines which operate at full speed only, this condition is not encountered because the engine is brought up to full speed immediately after starting and the flywheel has inertia enough to keep the engine running smoothly, even though ignitions are somewhat irregular.

9 In a marine engine the case is entirely different. Here it may be desired to start an engine slow ahead or astern, which, with a small, light, high-speed engine is difficult, unless a clutch between the engine and propeller permits the engine to be started up independently, warmed up, and then the clutch thrown in. The trouble in starting up when the engine is connected directly to the propeller is that in order to get the first ignition the fuel is turned well on, and when the first ignition does come there is enough energy in the combustion to overcome the inertia of the parts and drive the engine up to a much higher speed than is desired. With large, heavy engines this tendency is not nearly so marked and it is possible to get a slow, smooth start. Here the energy of the first combustion is not nearly as great in proportion to the mass of the moving parts.

10 There are several ways to assist in getting a smooth start on a cold engine, and it is important to follow one of them in the case of large engines. One method is to heat the jacket water by turning steam in from an auxiliary boiler. In this way the cylinder walls can be warmed up to something approaching the working temperatures, and a smooth start is easily made. Another method, particularly useful in installations where very heavy fuels are used, is to start with a lighter fuel. By a lighter fuel is meant one that ignites readily and is more easily broken up so as to expose more surface to the heated air in the cylinder in the compression space, and thus give a quicker ignition. The solution of the problem of getting a good smooth start consists essentially in having the temperature in the cylinders approximately the same as under working conditions and then injecting the fuel positively and regularly. Any method which does this will solve the problem.

11 Generally speaking, stationary engines, and marine engines with clutches between the engine and propeller, are fitted with starting valves on only half of the working cylinders. This means that while the engine is being turned over by starting air on part of the cylinders, the others are being warmed up by the compression, and

even under very adverse conditions they soon reach such a temperature that ignition is obtained. In the case of reversing engines the handling gear is sometimes modified to cause the starting air to be turned on and off the cylinders in groups.

12 The question of maneuvering is principally one of obtaining sufficient starting-air capacity, either by carrying a large number of flasks or — a much better way in the case of a large ship — by having an auxiliary compressor unit of good capacity. While the ship is maneuvering, the compressor unit is kept running all the time and pumps into the starting flasks. With such a provision an engine can be reversed repeatedly with only a very small starting-flask capacity.

13 In the case of small powers, it is much more convenient to use a clutch between the engine and propeller and employ a non-reversing engine which is kept running all the time.

14 The charge is often made against the Diesel engine that it is impossible to slow it down materially. This is true to a certain extent of the ordinary type of construction, but with the proper modifications any Diesel engine can be made to slow down and operate as readily at the lower speeds as at the higher. The solution of the problem consists in having a regular enough turning moment to keep the engine running fairly smoothly, and in obtaining definite and regular ignitions in the cylinders. The case is much simpler for a large, heavy engine which has a big mass in the moving parts, and where there are a larger number of cylinders, say, at least six for a two-cycle engine and eight for a four-cycle engine, than it is for a small, light engine.

15 In the propulsion of a ship the power drops off very rapidly as the revolutions are reduced, and therefore at very low speeds the power is so small that when divided up among all of the cylinders in the engine there is not enough fuel injected into each cylinder to give regular ignitions. This can be remedied in a large measure by cutting out half of the cylinders. The load per cylinder will then be more than doubled and the engine will run with very light loads at low revolutions.

16 Another method consists in the control of the spray-valve lift and timing by the operator. The control mechanism is so arranged that the timing and lift are changed at the same time. In some cases the valve is made to open at the same time under all settings and to close earlier, while in others it delays the time of opening by the same amount the time of closing is shortened. Both systems appear to work satisfactorily. When it is desired to slow

the engine down the fuel supply is reduced, the spray-valve lift reduced and the timing changed, and the spray-air pressure reduced somewhat. The combined effect of all these is to give regular ignitions in the cylinders, hence a smooth turning moment and good control over the engine. This method is much more preferable to cutting out some of the cylinders at reduced power, since it provides more impulses smaller in size and at closer intervals, which are all very vital points when running at very low speeds.

17 The advisability of fitting some sort of gear for controlling the timing and lift of the spray valve depends upon the type of engine and the place where it is going to be installed. Without such gear, an engine can be slowed down to about half speed without difficulty, hence for installations of small power in ships having a maximum speed of 10 knots or thereabouts it is unnecessary because half speed means little more than steerageway. On the other hand, in the case of ships having a higher maximum speed such as 15 or 20 knots, it is very desirable to be able to slow the engines down to quarter speed or less and then the installation of such a gear becomes almost a necessity. Under some circumstances, of course, it might be considered better to sacrifice maneuvering ability for the sake of simplification, but on engines of the size used on seagoing ships the slight added complication due to this gear seems every bit worth while.

18 The question of lubrication is one that is dependent upon the type of engine. The gravity system is used successfully on large open-frame slow-speed engines, while on the small sizes, particularly where the crankcase is enclosed, a mechanical oiler is often used with leads to separate bearings or else a system of forced lubrication. There is one difficulty with the gravity lubrication and the mechanical oiler, and that is, that there are many parts and pipes to consider, and each pipe or lead requires a certain amount of individual attention in order to see that the proper amount of oil is being supplied to that particular part. Furthermore, with these systems only just enough oil with a slight margin is provided to cover the necessary requirements of the bearing.

19 The big advantage of the forced-lubrication system is that a good surplus is supplied to each bearing at all times and distribution of the oil is secured by the proportions of the various passages, and hence requires no attention on the part of the operator other than to make sure that the main supply to the engine is kept up. Of course the various passages must be kept clear and open, but this is

a matter that can be readily attended to during the overhauling period and there is very little tendency for the oil to plug up the passages during operation.

20 There is one thing in connection with forced lubrication that is extremely important and requires constant watchfulness on the part of the operator, and that is the question of salt-water leaks into the lubricating oil. Any leak into the crankcase, no matter how small, forms an undesirable mixture with the lubricating oil and at moderate temperatures creates a deposit which will quickly plug up the passages. If special precautions are taken against the leakage of the salt water into the oil and the condition of the oil is watched carefully at all times, there is little chance for difficulty in this direction. From every other standpoint forced lubrication has the advantage over other methods. The proof of this is best shown by the increasing adoption of this system on engines of all types and sizes.

21 With an open-frame engine and using special precautions so that lubricating oil from the working cylinders does not drip into the crankcase, the oil does not become foul except after long service, but with the closed-crankcase trunk-piston engine the lubricating oil soon becomes fouled with finely divided carbon particles. After a time the oil turns very black and viscous and tends to clog the oil passages. This requires as much as 3000 hours' running in some cases, while in others this condition obtains in a few hundred hours. It is understood, of course, that oil is added from time to time to make up for the losses, but the system is not cleaned out and the whole supply replenished in all this time. As this condition of the oil is approached the danger of bearing troubles increases, and if it can be avoided the oil ought never to be allowed to get into such a condition.

22 Most of the carbon particles are removed by filtering and the filtered product approaches the original in all its properties except that it is darker, due to the presence of the particles which were not removed by filtering. The centrifugal process of clarifying is even better than filtering and removes a larger proportion of the carbon particles.

23 To attempt to filter or clarify the oil each time it is circulated through the engine would imply the addition of too much apparatus to take care of such a quantity of oil, and fortunately it is unnecessary. The best way is to drain out the system at regular intervals, depending upon the type of engine and the conditions of the service,

and fill up with fresh oil. The fouled oil can be filtered at leisure and kept for future use.

24 The Diesel engine industry is still so young that the question of how large an engine can be built is one that cannot readily be answered at this time. Practically all of the engines in service today are of small and moderate power as compared with certain steam plants, but, on the other hand, big strides have been made in the last few years in the development of large units.

25 In view of what has already been done and the experimental work that has been undertaken by so many firms, it is undoubtedly only a question of time when Diesel-engine power will be available for all except the very fastest liners and warships.

26 The vibration produced by an engine depends largely upon the number of cylinders and upon their arrangement. In commercial work, generally speaking, the speed is slow enough and the hull heavy enough so that the matter is not one of great importance, but in the case of a high-speed engine in a light hull, it is absolutely necessary that the engine be properly balanced.

27 For commercial work many four-cylinder four-cycle engines have been built, and these engines are very badly out of balance due to arranging the cranks all in one plane to get the best turning moment. But, as already stated, where these engines have been installed no serious difficulty has resulted, due undoubtedly to the relatively low revolutions and the small size of the engine as compared with the hull.

28 If good balance is desired, it is necessary to use six or eight cylinders, which can be made to give the best turning moment and a good balance at the same time. The only thing that interferes with giving these engines a perfect balance is the air-compressor cylinders, but the reciprocating parts of these compressor cylinders are comparatively light and hence do not cause any serious difficulty. In the case of crosshead engines it is oftentimes convenient to drive the compressors by beams and links from the crossheads. On a six-cylinder four-cycle engine, for instance, there might be three compressors driven from three of the cranks, or on a six-cylinder two-cycle engine three compressors would be driven from three of the crossheads and three scavenger pumps from the other three, so that a practically perfect balance would be obtained.

29 The usual method for the fuel system is to carry the main supply of fuel in the double bottom or in tanks in parts of the ship that are not ordinarily otherwise used, and then provide pumps for

pumping it into gravity tanks placed well up in the engine room so that the fuel can flow by gravity from the tanks to the engines. The tanks are made large enough to hold at least several hours' supply and oftentimes a whole day's supply, so that the fuel has plenty of time to settle and any sediment or water will collect at the bottom of the tank, where it may be drained off. It is very necessary that the fuel supply to the engine be perfectly clean. Very small particles of dirt or foreign matter will stick in the valves on the fuel pumps on the engine and cause no end of trouble. There is only one way to avoid getting this dirt into the engine and that is to filter the fuel properly. The filter is sometimes placed between the gravity tank and the engine and is sometimes combined with the gravity tank. In case the gravity tank is of small capacity, it is generally placed on the discharge side of the pump which pumps the fuel from the main tanks to the gravity tank.

30 The arrangement of the exhaust piping depends upon the type of the boat and the conditions of the installation. In the case of small boats where the water line is more or less fixed and very little rough water is encountered, an underwater exhaust works out very satisfactorily, but in the case of large ships the exhaust must be carried up a stack. In twin-screw boats it is essential that the exhaust from each engine be kept separate so that it can be watched by the operators. One of the simplest methods of detecting faulty operation in a Diesel engine is to watch the exhaust. The least sign of smoke is a sign of poor combustion and should be investigated at once.

31 Many varieties of muffler are used. The main idea of all of them is to break up the pulsations in the flow of the gases and give a steady flow. Where there is plenty of space and weight available, a big expansion chamber serves fairly well, but it is much better to reduce the size and use baffle plates. One of the best types is one in which the gases enter a cylindrical chamber tangentially at the circumference and escape at the center, or vice versa. Cooling the gases by turning the cooling water from the engine into the exhaust pipe helps, too, but is not used except in some special cases. If there is very much sulphur in the fuel, water combines with the products of combustion and forms sulphuric acid, which will in time destroy the exhaust piping. If, however, the entire quantity of the cooling water passing through the engine is turned into the exhaust, the mixture is so dilute that there is little danger of trouble.

32 The piping itself must be jacketed or lagged and due allowance must be made for expansion. Water-jacketing is in most cases more satisfactory but it adds to the complication and cost of the system and for that reason is oftentimes avoided and the pipes are lagged.

33 The question of cooling the various parts of a Diesel engine is an important one, but as far as the fixed parts are concerned the problem is simple for all ordinary sizes of engines. It is only necessary to provide for the proper flow of the cooling water, avoiding all pockets and dead areas. In the case of nearly all two-cycle engines and in four-cycle engines of quite moderate size it is necessary in addition to cool the working piston, and herein lies a real problem. There is no exact dead line below which cooling is unnecessary and above which cooling is necessary, as a great deal depends upon the conditions of operation; that is, a high-speed engine designed to be driven at a heavy overload might require cooling, while the same engine driven at a lower speed and moderate power would operate perfectly satisfactorily with uncooled pistons. It is simply a question of carrying away the heat absorbed by the top of the piston. If it can be carried off fast enough through the cylinder walls to keep the center of the piston head from getting too hot, then the pistons do not need to be cooled, but if this is not so, then the extra heat must be absorbed by the circulation of a cooling medium through the piston. In general, it may be said that two-cycle engines developing 50 b.hp. or more per cylinder and four-cycle engines developing 150 b.hp. or more per cylinder are better off with cooled pistons.

34 The difficulties in the way of successfully cooling the piston are best shown by the variety of substances used and by the various devices employed to carry the substance to and from the piston. The simplest method is to employ a jet of air, but this is not very effective and can be used only where the cooling effect required is very slight. The other three substances employed to any extent are lubricating oil, fresh water and salt water. Lubricating oil has the distinct disadvantage that its specific heat is only about 0.4 of that of water and hence about 2½ times as much must be circulated to carry off the same amount of heat within the same temperature limits. In addition, oil does not absorb heat from, or give heat to, a metallic surface as readily as does water. The one advantage of oil is that in case of any leakage inside of the crankcase it mixes with the other lubricating oil and does no damage.

35 In view of all this, it is readily understood why lubricating oil is used only in special cases where certain conditions make the advantages more than outweigh the disadvantages.

36 For commercial work it is safe to say that the choice lies between fresh and salt water. Fresh water requires an additional system including tank, pump, cooler and piping but it is not so corrosive, not so destructive to the packing in the joints of the system, not dangerous as regards deposits in the piston, and in case of leakage into the lubricating oil there is not the danger of damage to bearings. When salt water is used with proper precautions, most of the advantages of fresh water disappear, but it is a question as to how far these precautions can be successfully carried out under every day working conditions. Both fresh and salt water will undoubtedly be used for some time to come until enough experience is gained with both systems to finally settle the matter either one way or the other, or it may be that fresh water will be used for high-grade installations and salt water where first cost and simplicity are of prime importance.

37 To carry the liquid to and from the piston there are three general systems, but the details for any one system are varied greatly by the various engine builders or by the same builder on different engines. One system is to combine the cooling with the lubrication system as in Fig. 4, but this of course is applicable only in case lubricating oil is used for cooling. The general scheme is to supply the oil to the main bearings, from whence it passes through the hollow crankshaft to the crankpin bearings and up the connecting rods to the wrist pins, thence through pipes or passages in the piston to the head and back again through a pipe or passage to some point near the bottom of the piston, from where it can drain directly into the crankpit. A certain amount of oil leaks out at the bearings and this serves to lubricate them.

38 A second system is to use jointed swinging pipes and a third system, telescopic pipes. Both inlet and outlet pipes can be and are generally used so that any liquid desired can be employed for the cooling medium. The swinging pipes are suitable for slow-speed engines only, as at high speeds the inertia forces are very large and it is troublesome to take care of them properly. Moreover, the passage for the liquid must by the nature of the case have several bends and turns, and at high revolutions the inertia forces produce extremely high pressures, making it very difficult to keep the joints of the systems tight.

39 There is one principle that must be followed in the design of ·inging pipes for even moderate speeds, and that is to keep the arings at the joints of the pipes entirely independent of the stuff-g boxes, or in other words the piping for carrying the liquid and e strength members for taking the inertia forces must each do its vn work although they are fastened together and are a part of ch other. The great trouble with this system is to keep it tight at

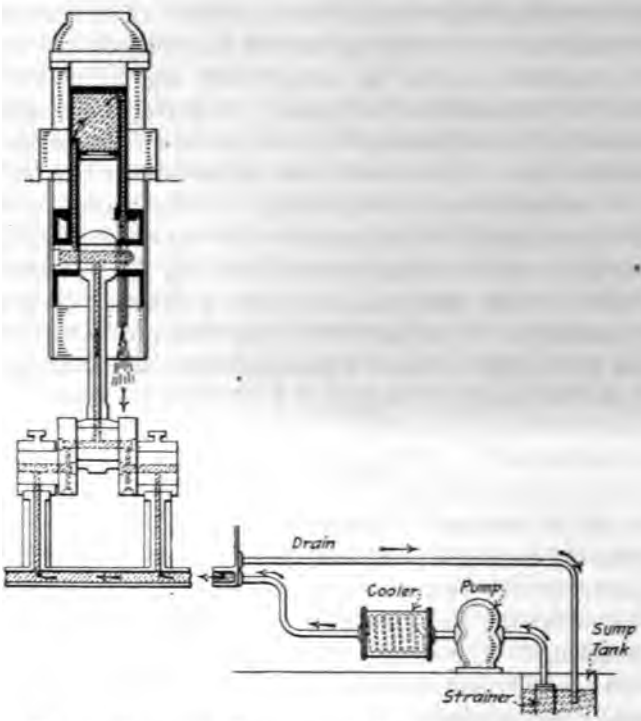


FIG. 4 COMBINED COOLING AND LUBRICATION SYSTEMS

e joints and it is only by careful designing along the lines stated at successful results can be obtained. In case water is used for a oling medium, the lubrication of the bearings at the joints becomes ıportant, but with forced lubrication there is generally enough l flying around in the crankcase to take care of this, if pockets, nnected to the bearings, are provided for catching it.

40 Telescopic pipes are adaptable to both high- and low-speed gines. All parts are moving in line with the cylinder axis and

RAYMOND C. FULLER (written). The automatic method of reversing described in Par. 1 is open to the criticism of all methods which employ several air pistons with interlocking functions. Since reversing is necessary only at the end of a voyage, the several air cylinders are liable to become stiff from temporary disuse and work badly when the need is greatest. This of course can be remedied by executing a few maneuvers to renew the flexibility of the system just before coming into port.

There are other schemes for reversing which are very reliable. One is to provide two sets of cams, one for ahead and one astern, on separate parallel shafts geared together and movable laterally. The maneuver is executed by moving the system of cams under the rocker rollers to bring the required set into play. This can be done manually or by steam, compressed air or electric power. In going from ahead to astern the cam system passes through a neutral point, at which time a device interlocking with the handling gear relieves all the compression in the cylinders. This enables the starting air to give the engine momentum against the first working compressions without overcoming the compression at the moment of stopping.

There is another method in which the ahead and astern cams are keyed rigidly to one camshaft. In this case reversing takes place by either lifting the rollers free of the cams and sliding the camshaft so the rollers index with the reverse set of cams, or by keeping the camshaft in the same position and swinging the rockers up and over to the reverse set of cams. In the case of a four-cycle engine the rocker shift is accomplished in the following way: The rocker fulcrums are eccentrics keyed to a common layshaft for the whole engine. The air-inlet, exhaust and starting-air rockers are on eccentrics which are fastened askew on this layshaft with the angle between their axis and the axis of the layshaft approximately equal to half the angle necessary to swing them to the reverse position. The fuel rocker is on an eccentric with axis parallel to the layshaft and is of sufficient throw to carry the roller to reverse relation with the cam nose. It is necessary to provide two points of contact between the air-inlet, exhaust and starting-air valve stems and rockers to take care of the two positions of the rockers. The valve end of the fuel rocker is a slot through which the top of the valve stem slides. By turning the layshaft the eccentrics lift the rockers and throw them over through a neutral position to the reverse position. The starting cams operate at an intermediate position and swing out of the way for normal working conditions. In the case of two-cycle

engines with scavenging ports at the bottom of the piston stroke instead of scavenging valves in the head, it is only necessary to reverse the air-inlet and fuel-valve functions. This is easily accomplished by changing the relation between the cams and rollers by providing transition slopes on the sides of the cam noses for the rollers to travel on when they dismount and mount the cams when the camshaft is brought to a reverse position by a longitudinal shift.

In maneuvering with compressed air in the working cylinders the two-cycle engine has ordinarily much the advantage in turning effort over the four-cycle. This disadvantage in the four-cycle can be overcome by arranging it to function as a two-cycle engine in starting. In addition to using a two-nosed starting cam, an auxiliary arm with a roller on the exhaust rocker is cut in on an auxiliary exhaust cam with the nose set at 180 deg. from the main exhaust cam. With the inlet valve cut out of action the engine runs two-cycle on starting air.

No matter what system of direct reversing is used, there are expensive and intricate complications over what is necessary for the non-reversible type. It would be well to give considerable thought to the electric drive or the hydraulic transformer in connection with the marine Diesel engine. Unlike reversing clutches, these intermediary controlling devices have no limit to their size. They are of themselves costly, but there are compensations in the reduced cost of non-reversing Diesel engines in many ways. Complicated handling gear and immense starting air tanks could be dispensed with. Direct drives require engines with speeds suitable to the propeller. Indirect drive can make the more economical use of higher engine speeds and consequently a lighter, less costly engine. The repairs and lost time which in many cases can be attributed to damages to the engine through maneuvering would go a long way toward paying the extra cost of an indirect drive. The use of reduction gears would be a logical step in taking advantage of the increased engine speed, but there is no maneuvering advantage in this scheme. We should never forget that cost per deadweight-ton-mile is the criterion for economy for a ship and, in connection with this, huge repair bills and lost time count heavily against low unit costs. For this reason the foregoing means of utilizing the marine Diesel seem worth our attention.

The expansion of compressed air into the working cylinders is bad in two ways. The freezing effect on the hot walls is likely to, and often does, produce cracks. The expanded air recompressed in the

case of the two-cycle engine does not produce a satisfactorily high temperature to insure the positive ignition of the fuel, and in the case of the four-cycle the temperature for ignition is not as high as if no starting air were used in the working cylinders. Cylinder liners which are hard enough to withstand excessive wear are likely to crack due to rapid temperature changes.

My experience has been that the best maneuvering engines are those which do not start on compressed air expanded in the working cylinders. Those which use compressed air in this way consume excessive amounts for this purpose. The more reliable and efficient way is to maneuver by means of the air compressor in the case of four-cycle engines and the scavenge pump in that of two-cycle. Two or more compressors on a four-cycle engine can have the cranks set to give a good starting moment on the shaft and if necessary the low-pressure cylinders can be double-acting. By valve manipulation the expansion of starting air in the low-pressure cylinders of the air compressors will turn the engine in the desired direction until the first working stroke is made. The power stroke is usually the first or second possible, so the starting air can be shut off early in the process. The same idea is carried out in the scavenge pumps on two-cycle engines. The thought in both cases is to allow the working cylinders to function only as such at the first possible instant in a maneuver and not be required to have the starting air expanded in them with the resultant cooling effects then switched over to fuel. Many times the fuel does not ignite at first because the recompressed expanded air does not produce a high enough temperature. The starting air used in the compressor or scavenge pump can be used as a cushion in bringing the engine to a standstill and thus make a quicker reversal possible. It is obvious that the quicker the engine is reversed the more economical it will be in the use of starting air.

Referring to Par. 10, there is another thought to be added to the idea of starting on light oil, and that is, to stop on it. The combustion conditions, atomization and temperature conditions in maneuvering are rather poor, so that with heavy oil carbon deposits are liable to form. By using light oil in maneuvering and for a period before stopping, not only is the formation of carbon deposits prevented but that already formed is burned in the presence of the more perfect combustion of the light oil. Fuel pumps are easily arranged to switch from one kind of oil to another.

The point raised in Par. 16 in regard to the consumption of fuel-injection air in relation to time of opening and valve lift is very well

considered. The following way of obtaining the change in both lift and timing of the fuel valve is very simple in the case of a two-cycle engine. By making the cam movable axially in relation to the cam roller, the nose of the cam can be constructed to obtain a variation in lift and time for the various positions. The nose of the cam is made with a taper from full form gradually down on one side to the body of the cam in the direction of the axis. It will be full form with approximately a conical surface at one side. This form will be at both ends of the cam, at one for ahead and the other astern so that the change from one way to the other can be accomplished by a gradual transition through a neutral point. This same arrangement can be used on a four-cycle engine by using a separate camshaft for the fuel levers. The conical surface can be so designed as to give any desired relation between lift and timing. The result is so easily obtained that it should not be prohibitive for small-power engines. It is advisable in most cases to use a separate fuel pump for each cylinder so that each will receive a definite controllable supply of oil.

This leads to governing. The individual fuel pump operated by a variable-throw eccentric provides an excellent means of governing. Any reliable form of speed regulator to change the throw of the eccentrics simultaneously produces good results. Governing is especially desirable for Diesel engines on large boats which travel on rough seas where the propeller comes out of the water at times enough to allow the engine to race.

In using the word "success" in connection with Diesel engines, we should do so in the broadest sense of the word. When a private concern can produce under competitive conditions a marine Diesel engine which it can sell at a profit to a merchant ship owner who in turn finds it to be a profitable investment after a reasonable time for repairs, replacements and other things of this nature to develop, then can we say it is a success. Large marine Diesel engines have proved costly to build on account of the additional precautions necessary for taking care of piston and cylinder cooling, high pressures on large surfaces, complicated handling gear, and many other features. If practicable, it would be of service to engineering in its broadest sense to ascertain the cost of the engines for the *Maumee*, taking into account the overhead costs in addition to those of labor and material in the same way that a private concern must do to stay in business. Then we would be able to judge whether or not the expenditure in this case would be justified or not for this size of engine for merchant ships.

From my experience with various types of propelling machinery, it is my opinion that twin-screw vessels can be successfully equipped with Diesel engines up to 3500 b.hp., but beyond this point lies the field for high-speed turbines with double-reduction gears for some time to come.

In regard to settling tanks for removing water and the heavier impurities from fuel oil, a tank with alternate baffles fastened to bottom and sides with the others fastened to top and sides so as to form successive traps for the impurities, works very well. Heating the discharge from this tank as it passes through the filter accelerates the separation of the dirt from the fuel oil. The use of spare filters is advisable, so that one may be cleaned while the others are in commission.

THE AUTHOR. It is to be regretted that more complete information is not at hand to answer Mr. Shaw's suggestion in regard to details of the actual performances of the *Maumee*. The minor troubles referred to in the paper were those experienced during the early months of her career. They consisted of a cracked cylinder water jacket due to improper fitting of the liner in the jacket and of troubles with air-compressor valves due to feeding too much lubricating oil to the compressor cylinders. This latter trouble was entirely eliminated as soon as the operating personnel had had a little more experience. As for the cylinder heads, three different types were tried, and according to the best information at hand all of them have proved to be entirely satisfactory. The three types consisted of a single-piece cast-iron head, a two-piece forged-steel and cast-iron head, and a single-piece bronze head.

There is no intention whatever of claiming that the *Maumee* was a pioneer motorship, but the point is that the successful operation of engines of that power indicates that Diesel engines of sufficient power to drive practically any size of ocean-going cargo vessel now built are available. The number of successful motor cargo ships is increasing steadily and very rapidly, but by far the greater majority of them have engines developing a total shaft horsepower of 2500 or less, which is about half that of the *Maumee's* engines. There is no reflection on the builders of these ships in this, but it is rather a result of conditions and an indication of the sound engineering judgment of the builders. They have wisely started with engines of small powers per cylinder, and have undertaken the construction of larger engines as they gained experience. Fortunately the power

required to drive these motorships has been such as to permit this procedure. In the case of the *Maumee*, however, the power required to meet the conditions meant the construction of engines much larger than any in operation at that time. It has been recently reported, however, that engines much larger than even these are now under construction and will be in operation within the year.

The method of controlling the spray air pressure in use on the Burmeister & Wain engines as described by Mr. Shaw is very interesting and is no doubt entirely satisfactory for cargo-ship installations, since the maximum speed does not exceed 12 or 13 knots and the ability to slow down the engines to half-speed or a little less is ample for maneuvering, but in the case of a 15- or 20-knot ship it is very convenient to be able to run the engines at one-third or one-quarter speed, and then the fitting of some sort of gear to control the timing and lift of the spray valve is almost a necessity.

There is no doubt but what the closed crankcase and crosshead type of engine is very satisfactory using forced lubrication on all the principal bearings. The construction is perhaps a little heavier and a little more expensive than some others, but its superiority from the operation stand-point is ample justification.

The criticism of the pneumatic system of reversing suggested by Mr. Fuller is true to a certain extent, but experience has shown that with proper care there is, after all, very little difficulty with this system. On the other hand, the mechanical system of reversing and valve control with various modifications is much more universally used.

There have been several attempts made already to obtain the benefits of the Diesel engine as applied to ship propulsion without the expense of fitting the large and costly engines required by direct connection to the propellers. Reduction gears have been used in at least two cases and reports state that the rather brief experience to date has been very satisfactory. The electric drive with moderately high-speed engines directly connected to generators which in turn furnish power to the motor on the propeller shaft is not a new proposition but still there have been very few commercial applications. This system has many advantages, such as lighter, cheaper and simpler engines, great flexibility of control, freedom from complete breakdown due to duplication of power units, and adaptability to large powers through the use of several moderate-size power units. The one important disadvantage is the higher fuel consumption due to the electrical losses. This same disadvantage applies also to the hy-

draulic transformer. Time alone will determine whether or not these other systems offer enough advantages over the direct connected installation to justify their permanent adoption.

Mr. Fuller is absolutely right in urging that the word "success" be used in its broadest sense in connection with Diesel engines. The construction of the large marine Diesel engine is hardly beyond its infancy in this country at present and consequently the costs of construction are necessarily high. But even so, the Diesel-engined motorship is more economical than the steamship, as is proved by the ever-increasing number of motorships being built.

The small marine Diesel engine has already firmly established itself, and as time goes on and experience is gained larger engines will just so surely be adopted in increasing numbers.

No. 1663

THE COOLING LOSSES IN INTERNAL-COMBUSTION ENGINES AS AFFECTING DESIGN

By C. A. Norman, Columbus, Ohio
Member of the Society

From experiments by Dugald Clerk and others the author derives a formula giving the cooling loss during the expansion stroke of internal-combustion engines in terms of the surface-to-volume ratio, the revolutions per minute and the piston speed of the engine. With the aid of this formula the effect of varying dimensions, stroke-to-bore ratio, expansion ratio and piston speed is investigated. Great expansion combined with a low stroke-to-bore ratio is found in general conducive to best efficiency. Large size, as well as very high speed, will in general reduce efficiency: large size by necessitating a low number of revolutions and extremely efficient cooling; very high speed by delayed combustion. The best speed and dimensions to be used in every individual case can be estimated by the aid of the formula.

The author's formula is based on certain simple theoretical considerations. It derives its practical justification, however, from the fact that it gives results in close agreement with the only published experiments on the subject which have been thoroughly criticised. Further experiments are highly desirable, but under present conditions will probably be long delayed and for high-speed engines will be found extremely difficult to carry out. Under these circumstances, the formula is offered merely as a basis for estimating as closely as can be done, at the present time, the extent to which cooling losses depend upon engine speeds and dimensions. The importance of such information for intelligent judgment about possible engine performance and intelligent design for high efficiency need not be dilated upon.

THERE is considerable evidence that a great part of the heat loss to jacket water in an explosion engine occurs, not during the expansion stroke, but rather in the exhaust passages. Coker found by direct measurement a temperature drop of 150 deg. cent. (270 deg. fahr.) between the gas in the cylinder at the end of the expansion stroke and the gas in the exhaust pipe. Dugald Clerk found indirectly that of a total measured jacket loss of 25.4 per cent, about 16 occurred in the cylinder, and consequently 9.4 per cent in the

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exhaust passage.[1] Losses in the exhaust passages, however, have no influence on the thermal efficiency of the engine. In order to arrive at the influence of varying proportions and speeds on the efficiency it would be necessary to determine separately the losses during the expansion stroke for a whole series of engines, varying only one factor at a time. No such investigation has to the knowledge of the writer been undertaken.

2 Clerk, however, has determined very carefully the losses with varying temperature in one engine, and his results, combined with other material, most of which will be found reported in his treatise on gas engines,[2] can be made applicable also to other engines.

3 The formula for cooling loss developed later by the author from the published work of Clerk and others, while in form based on

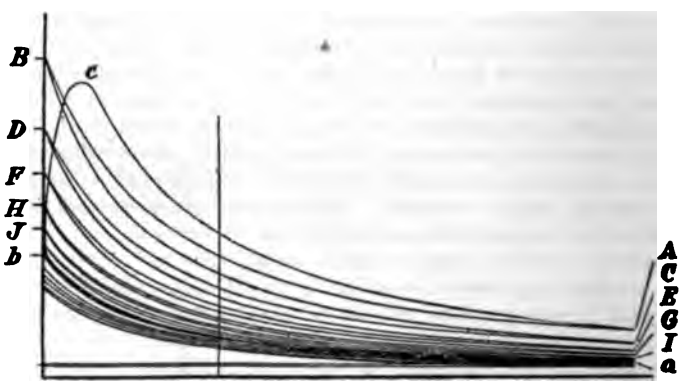

FIG. 1 CLERK DIAGRAM OF EXPLOSION AND ALTERNATE COMPRESSION AND EXPANSION OF HOT GASES IN ENGINE CYLINDER

theoretical considerations, has nevertheless been found to represent fairly both the results of careful experiments and general experience, and its presentation at this time would therefore seem to be justified.

METHOD EMPLOYED BY DUGALD CLERK IN HIS EXPERIMENT

4 Clerk equipped an ordinary gas engine with a contrivance enabling him momentarily to close the inlet and exhaust valves

[1] For a complete as well as succinct statement of these losses, as also of most other experimental facts referred to in this paper, the reader is referred to the Gustave Canet Lecture of Dugald Clerk, *Engineering*, July 4 and 11, 1913, pp. 28 and 58.

[2] Dugald Clerk, The Gas, Petrol and Oil Engine, John Wiley & Sons, Inc., Vol. I., 1909, Vol. II, 1913.

hile the engine continued to run. A series of recompressions and eëxpansions of the same burned charge took place in the cylinder. A sample diagram of these fluctuations is given in Fig. 1.

5 With no cooling and no friction losses the recompression ought always to carry the gas temperature back to its value at the beginning of the previous expansion. As a matter of fact, Fig. 1 shows a constant falling of the temperature from point B to points D, F, H, etc. By means of calculation or determination of the temperature at one point, definite temperature values can be assigned to all the other maximum- and minimum-pressure points on the diagram and an estimate of the actual temperature drops and the

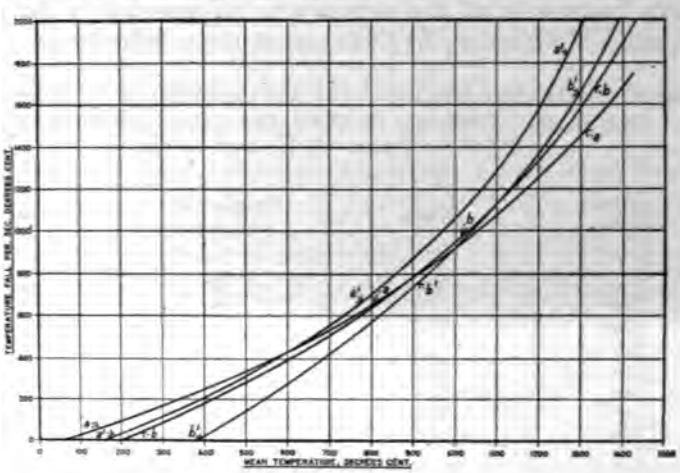

FIG. 2 TEMPERATURE DROP INCURRED PER SECOND AT DIFFERENT MEAN TEMPERATURES CALCULATED IN TIME. EACH LINE IS THE MEAN OF THREE CARDS UNDER THE GIVEN CONDITIONS

120 r.p.m. Cold { (a) Whole stroke; (a′) Upper $\frac{3}{10}$ stroke } 160 r.p.m. Hot Load 50 b.hp. { (b) Whole stroke; (b′) Upper $\frac{3}{10}$ stroke }

average temperatures during the strokes can be made. With the aid of the speed of the engine it is also possible to give the results in terms of reduced temperature drops per second corresponding to certain average temperatures. The results are given in the form of the curves reproduced from Clerk's work in Fig. 2.

6 These curves show reduced temperature drop per second in the engine running light at 120 r.p.m. for a full expansion stroke (a) and for the upper $\frac{3}{10}$ expansion stroke (a'). Also for the engine running loaded at 160 r.p.m. for the full expansion stroke (b) and during the upper $\frac{3}{10}$ expansion stroke (b'). The inter-

section of the curves with the temperature axis gives the mean temperature of the wall. There are, then, four curves referring to two different ratios of cooling surface to included volume and to four different wall temperatures. It will be noticed that the average wall temperature for the whole stroke is only about 60 deg. cent. (140 deg. fahr.) at light load, and 200 deg. cent. (392 deg. fahr.) at heavy load. At heavy load the average temperature of the combustion space and adjacent parts is as high as 380 deg. cent. (720 deg. fahr.)

7 At the range of average gas temperatures occurring during ordinary full-load conditions, the curve *b* probably represents the cooling losses with all the accuracy to be expected in the present connection. No other curve will henceforth be referred to.

TABLE 1 APPARENT SPECIFIC HEAT (INSTANTANEOUS) AT CONSTANT VOLUME, C_v, EXPRESSED IN FT-LB. PER CU. FT. OF WORKING FLUID AT 0 DEG. CENT. AND 760 MM.

Temperature, deg. cent.	C_v ft-lb.	Temperature, deg. cent.	C_v ft-lb.
0	19.6	800	26.2
100	20.9	900	26.6
200	22.0	1000	26.8
300	23.0	1100	27.0
400	23.9	1200	27.2
500	24.8	1300	27.3
600	25.2	1400	27.35
700	25.7	1500	27.45

8 The curves in Fig. 2 give temperature drop, not heat loss. The expansion work in an engine cylinder is directly connected with the temperature drop by means of the specific heat. On the other hand, the work can be directly evaluated from the indicator diagram. In this way the specific heat of the gas in the cylinder at various temperatures can be ascertained.[1] Clerk gives the values found in Table 1.

9 Table 1 gives a striking illustration of the increase of the specific heat with the temperature. This increase is not uniform, however. It is considerable at lower temperatures, but almost nil at higher temperatures. Clerk in his original paper deems this behavior partly due to delayed combustion and hence considers his specific heat values as merely "apparent."

[1] See Proceedings of the Royal Society, A. vol. 77, p. 499.

10 Very thorough investigations of the specific heats of gases have been carried out by Nernst and his pupils.[1] From these it would appear that only carbon dioxide with certainty behaves in the manner indicated by Clerk's experiments. The specific heat of all other common gases, even that of superheated steam of sufficiently high temperature, shows rather a linear increase with the temperature. For the mixture used by Clerk the specific-heat values he gives seem to be too high, at least at lower temperatures. This is the opinion also of the Gaseous Explosion Committee of the British

TABLE 2 SPECIFIC HEAT OF CLERK'S WORKING MIXTURE

Temperature		Specific heat in B.t.u. per lb. or cal. per kg.	
Deg. fahr.	Deg. cent	According to Clerk	According to Nernst
32	0	0.180	0.178
212	100	0.192	0.183
392	200	0.202	0.187
572	300	0.211	0.192
752	400	0.219	0.196
932	500	0.228	0.201
1112	600	0.231	0.205
1292	700	0.236	0.210
1472	800	0.240	0.214
1652	900	0.244	0.219
1832	1000	0.246	0.223
2012	1100	0.248	0.228
2192	1200	0.250	0.232
2372	1300	0.251	0.237
2552	1400	0.2515	0.241
2732	1500	0.252	0.246

Association.[2] Yet, as will be seen above, the deviations are not very great, considering the accuracy possible. By means of his heat values Clerk has succeeded in accounting very satisfactorily and in a new and striking manner for the heat balances in several combustion engines. In the illustrative examples figured in this paper these values have at times been used. This can be done without question when only general laws for design are to be established.

11 Clerk gives the average composition of his combustion gas as follows:

[1] See Nernst, Theoretische Chemie, 1913, p. 267.

[2] See, for instance, Gustave Canet lecture of Dugald Clerk, *Engineering*, July 4 and 11, 1913.

	Volumes
Steam (assumed gaseous)	11.9
Carbon dioxide	5.2
Oxygen	7.9
Nitrogen	75.0
	100.0

12 The molecular weight of this mixture would be 27.96, or practically that of pure nitrogen, and the weight of 1 cu. ft. at 0 deg. cent. and 760 mm., 0.078 lb. The specific heat for the mixture at various temperatures is given in Table 2, in customary units, the

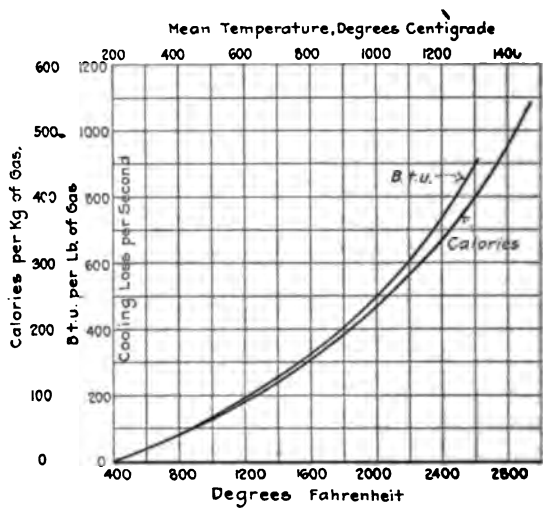

FIG. 3 COOLING LOSS PER SECOND AND UNIT WEIGHT OF GAS FOR FULL STROKE IN CLERK EXPERIMENTAL ENGINE

values having been derived both from the Clerk and the Nernst values.

13 The difference between the two series of specific-heat values given in Table 2 amounts to about 10 per cent in the middle of the range, but is barely 1 per cent at atmospheric temperature and less than 2.5 per cent at 1500 deg. cent. (2700 deg. fahr.). With the aid of Clerk's specific heats the cooling curves in Fig. 3 have been obtained.[1] These curves give the cooling loss during the whole

[1] The specific-heat values of Clerk have been deduced from work actually done by the gases in his engine. They give, therefore, the heat or energy equivalent of a certain temperature drop in this engine, and should be used in obtaining heat losses from measured temperature drops therein.

expansion stroke, reduced, however, to heat units per unit weight of gas per second. If, then, we compute the work theoretically obtainable from 1 lb. of gas with the temperatures and the expansion occurring, and if we compute the heat necessary to raise 1 lb. of gas from the temperature at the end of compression to the temperature at the end of the explosion, we can derive the actual expansion work as well as the percentage cooling loss. This, however, applies only to the Clerk engine.

TABLE 3 EXPLOSION EXPERIMENTS WITH CLOSED VESSELS

Reference No.	Experimenter	Capacity of vessel, cu. ft.	Internal surface of vessel, sq. ft.	Ratio of surface to volume, sq. ft. per cu. ft.
1	Hopkinson (large vessel)	6.2	17.3	2.79
2	Bairstow and Alexander Hopkinson (small vessel)	0.82	5.02	6.12
3	Hopkinson (small vessel)	0.684	4.33	6.33
4	Clerk (first vessel)	0.183	1.79	9.78
5	Massachusetts Institute of Technology	0.180	1.79	9.94
6	Clerk (second vessel)	0.150	1.60	10.65

TABLE 4 DROP IN TEMPERATURE IN 0.05 SECOND AT MEAN TEMPERATURES GIVEN, DEG. CENT.

Pressure before explosion in all vessels, atmospheric

Reference No.	Ratio of surface to volume ,sq. ft. per cu. ft.	Drop in temperature in 0.05 sec. at mean temperature of			
		1450 deg. cent.	1400 deg. cent.	1300 deg. cent.	1150 deg. cent.
1	2.79	80	68	52	38
2	6.12	127	114	93	65
3	6.33	166	153	131	100
4	9.78	378	327	257	182
5	9.94	372	327	257	182
6	10.65	238	216	184	138

APPLICATION OF CLERK'S HEAT-DROP CURVES TO OTHER ENGINES

14 *Influence of Surface-to-Volume Ratio.* Clerk's experimental engine had the following dimensions:

Cylinder diameter, in. 14
Stroke, in. 22

Total cylinder volume with full-out piston, cu. ft....	2.41
Total cooling surface with full-out piston, sq. ft.....	11.20
Sq. ft. of cooling surface per cu. ft. of volume.....	4.64

15 Now, the most simple assumption to make with regard to cooling losses is that they vary directly as the ratio of surface to included volume. For this assumption there is considerable support in the results of experiments with explosions in closed vessels. Table 3 gives data on the surface and capacity of the vessels used by several different experimenters, and Table 4, values of the temperature drop in the same vessels as recorded by Clerk.

16 The values in Table 4 have been plotted in Fig. 4. The experiments were carried out at widely differing places and times by

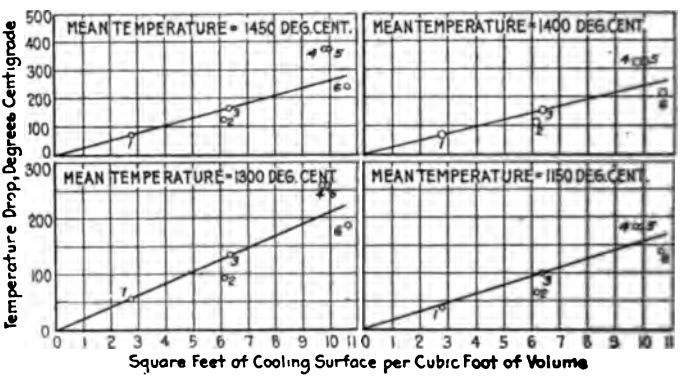

FIG. 4 EXPLOSION EXPERIMENTS WITH CLOSED VESSELS: DROP IN TEMPERATURE IN 0.05 SEC. AT MEAN TEMPERATURES GIVEN; PRESSURE BEFORE EXPLOSION, ATMOSPHERIC

different experimenters, using different methods, with vessels of differing shapes. It should not cause any surprise that the points are scattered. Nevertheless, it can hardly be denied that they are more naturally represented by straight lines, as shown, than in any other manner.

17 As far as experimental evidence goes, it then certainly seems to counsel the assumption of direct proportionality between heat loss per unit time and the ratio of surface to included volume. For geometrically similar vessels this ratio varies inversely as the linear dimensions. For similar engines running at the same number of revolutions the cooling losses would then vary inversely as the cylinder diameter. This has led to the conclusion that the cooling losses could be reduced almost to zero by employing sufficiently

ırge dimensions. How unjustified this is, will appear after some urther scrutiny.

18 *Influence of Speed.* In the derivation of the heat-loss curve rom Clerk's experiments it has been tacitly assumed that the heat ɔss varies directly as the time. No other assumption with regard o heat transfer has ever been made. With all other conditions qual, the heat loss in an engine should then vary inversely as the .p.m. It is important, however, to note that all other conditions hould be equal. It is known that if an engine is speeded up, somehing may be gained in efficiency, yet not as much as should be xpected if the heat loss dropped in direct proportion to the increase ı speed. The reason for this is often given as increased turbulence ıith increased speed. This would of course increase the convection ɔsses. If the valves are correctly located and correctly proportioned here should be no more turbulence at high speed than at low speed, nless the turbulence is intentionally increased in order to accelerte combustion.

19 For the same engine, an increase in r.p.m. means an increase ı piston speed and an equal increase in gas velocity along the walls. 'he old idea was that the coefficient of heat transfer from gases ıcreased directly as the square root of the rubbing velocity of the as. We can probably do no better in the present connection than dhere to this old idea, even though it expresses the relations somehat too simply. We should then put the heat loss directly proortional to the square root of the piston speed. Consequently, if he known heat loss of a certain engine be denoted by L_0, and its ırface-to-volume ratio and its piston speed, and r.p.m. by R_0, V_0 nd N_0, respectively, then for another similar engine with values ', V, and N, working under the same temperature conditions the eat loss

$$L = L_0 \times \frac{R}{R_0} \times \frac{N_0}{N} \times \sqrt{\frac{V}{V_0}} \quad . \quad . \quad . \quad . \quad . \quad . \quad [1]$$

20 This might be checked up on the experiments undertaken y the British Institution of Civil Engineers with three engines of milar proportions but of different size.[1] One of these engines — ıe largest one — appears to have been identical with the Clerk ɛperimental engine dealt with in this paper. Table 5 gives the ıain dimensions of these engines, as well as the r.p.m. and the .hp. developed at test.

[1] Clerk, Gas, Petrol and Oil Engines, vol. 1, p. 247, et seq.

21 For these three engines Dugald Clerk, who was a member of the investigation committee, gives the following as the most probable values of the indicated horsepower in per cent of total heat supplied:

Engine	*L*	*R*	*X*
I.hp., per cent	31.8	33.7	34.7

22 By means of his diagram method he arrives at about 16 per cent as the most probable average value of the cooling loss during the expansion stroke for the *X* engine. Applying Formula [1] to this value we find the following:

Engine	*L*	*R*	*X*
Figured cooling loss, per cent	19.9	17.9	(16)
Excess over 16 per cent as figured	3.9	1.9	..
Excess from i.hp., measured	2.9	1.0	..

TABLE 5 DIMENSIONS OF ENGINES TESTED BY BRITISH INSTITUTION OF CIVIL ENGINEERS

Designation of engine	*L*	*R*	*X*
Cylinder diam., in.	5.502	9.00	14.008
Stroke, in.	10.00	17.03	22.09
Ratio of stroke to bore	1.82	1.89	1.57
Clearance, per cent of total volume	17.94	18.02	18.50
Surface-to-volume ratio, sq. ft. per cu. ft.	10.7	6.52	4.62
B.hp. at test	5.2	20.9	52.7
R.p.m. at test	258.9	203.6	165.8
Piston speed at test, ft. per min.	431	577	607

23 It must be admitted that the agreement is about as good as could possibly be expected with engines of so widely varying dimensions. The agreement, for that matter, is still better if instead of Clerk's values for the indicated horsepowers we adopt these reported by the Committee as a body. These are:

Engine	*L*	*R*	*X*
I.hp., per cent of heat	31	32.9	34.8
Difference from value for *X*	3.8	1.9	..

24 The agreement with the figured values is almost exact. Too much importance, of course, should not be attached to this close agreement. Yet, in the absence of other methods of figuring cooling

losses, the use of the simple formula here derived would not seem irrational.

25 In the form just given the formula is serviceable only for comparing with each other engines working under similar temperature conditions, with similar fuels. It does not take into account variations in expansion ratio, or in maximum temperature; nor does it give absolute heat losses in heat units per unit weight of gas. It can easily be given this added range of usefulness by connecting it with the heat losses per second per unit weight of gas given for varying mean temperatures for the Clerk engine by the curve in Fig. 3.

26 Assuming a certain maximum temperature, or calculating it approximately with the aid of the specific heats given in Table 2, it is possible then to estimate from the expansion ratio of the engine the temperature drop during the expansion by the use of an assumed polytropic exponent. From this we get close enough for our purpose the mean temperature during expansion as an arithmetic average. The corresponding heat loss C is read from the curve in Fig. 3 and it is the loss in B.t.u. per pound or calories per kilogram of gas used for an expansion stroke lasting one second. To get the loss for any other duration of stroke it is simply necessary to multiply C by the actual duration. If the actual r.p.m. is N, this duration is $30/N$. The surface-to-volume ratio in the Clerk engine was 4.64 sq. ft. per cu. ft., and the piston speed at 160 r.p.m., — the speed at which the curve applies, — 586 ft. per min. Consequently, for any engine of surface-to-volume ratio R and piston speed V the expansion cooling loss in heat units per unit weight of gas used is

$$L = C \times \frac{30}{N} \times \frac{R}{4.64} \sqrt{\frac{V}{586}}$$

or

$$L = 0.267\,(CR/N)\sqrt{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

27 In Formula [2] R is expressed in sq. ft. per cu. ft., V in ft. per min., and N in r.p.m., while C can be either in B.t.u. per lb., or cal. per kg., or in any other units for which a C curve is available.

28 In these days of rapid internationalization, with cordial interchange of ideas between France and the English-speaking countries, especially in the field of aeronautical engines, it may be advisable to give the formula also in metric units, as follows:

$$L = 1.14\,C\,(R/N)\sqrt{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

where R is in square meters per cubic meter and V in meters per second, or

$$L = 114\,(CR/N)\sqrt{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

where R is in square centimeters per cubic centimeter and V in meters per second.

29 Finally if R should be given in sq. in. per cu. in., which is more convenient in most cases,

$$L = 3.2\,(CR/N)\sqrt{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

where V is the piston speed in ft. per min. as is customary.

APPLICATION OF THE COOLING-LOSS FORMULA TO ACTUAL CASES

30 *Influence of Absolute Dimensions on Cooling Losses.* Assume in the first instance that the piston speed does not vary. Particulars of series of such engines for a piston speed of 1000 ft. per min. and a bore-to-stroke ratio of 1 : 1.5 are given in Table 6.

TABLE 6 ENGINES WITH PISTON SPEED OF 1000 FT. PER MIN. AND STROKE-TO-BORE RATIO OF 1.5

Diameter, in.	3	10	15	30	42
Stroke, in.	4.5	15	22.5	45	63
R.p.m.	1333	400	266	133.3	95

31 In this case the r.p.m. varies inversely as the diameter, and so does the surface ratio. Consequently for the same C, L is constant. Thus, as far as the formula for the same expansion ratio and the same maximum temperature goes, the cooling losses and hence the indicated efficiency of these engines would be the same for all dimensions. Actually in order to avoid cracking of the metal, the cooling will have to be much more efficient for the larger engines. If they are double-acting, then even the pistons will be water-cooled. Even so, the maximum temperatures and maximum pressures will have to be kept down. The larger engines will therefore have a tendency to be rather less efficient than the smaller ones. On the other hand, with very high values of N the combustion is likely to consume a large part, if not the whole, of the stroke. In many cases, in fact, a good deal of the combustion will take place in the exhaust pipe. This can be prevented by extremely efficient carburization and ignition. Yet, on the whole, the likelihood is that, with the same compression, the best efficiencies will be found in the middle of the range. This would seem to be borne out by experience.

32 It may, however, be said that unvarying piston speed for ıll dimensions does not correspond to actual conditions. In some ıeroplane and automobile engines piston speeds are found approach-ng, if not exceeding, 2000 ft., while it might perhaps be conserva-ive to let the piston speed of very large engines remain below 750 't. Suppose that at the large-size end, the piston speed is half of what it is at the small-size end. The number of revolutions at the arge-size end would be only half of what it would have to be to imit the cooling loss to its value at the small-size end, piston speeds ›eing equal. This would tend to make the cooling loss twice as arge at the large-size end. On account of the lower value of the ›iston speed this loss is reduced in the ratio of $\sqrt{2}$. The upshot is ›hat the loss would be about 40 per cent greater for the large size.

'ABLE 7 ENGINES WITH UNVARYING VOLUME AND VARYING STROKE-TO-BORE RATIO

Ratio, stroke to bore	1.0	1.2	1.4	1.6	1.8	2.0	2.5
Diameter, in.	5.3	5.0	4.74	4.53	4.35	4.2	3.9
Stroke, in.	5.3	6.0	6.63	7.25	7.81	8.4	9.75
?, sq. ft. per cu. ft.	12.7	12.8	13.1	13.3	13.5	13.8	14.3
Piston speed, ft. per min.	1060	1200	1326	1450	1562	1680	1950
Cooling loss, per cent (for Clerk engine 16%)	7.85	8.4	9.05	9.6	10.1	10.8	12.0

33 There is then absolutely no reason to look for high efficiency n large dimensions. High speed, even though connected with high ›iston speeds, is preferable, even from the pure efficiency point of ›iew — provided the combustion can be effected satisfactorily. Strangely enough, the simple investigations here carried out will ;ive as a sort of by-product, some indications as to what it is neces-ıary to assume in regard to combustion.

34 *Influence of Varying Stroke-to-Bore Ratio.* In this para-;raph it will be assumed that the change in stroke-to-bore ratio is ıot consequent upon a change in expansion ratio. The question is: Vith a given expansion ratio and temperature range, how should a ;ylinder be proportioned for best efficiency? A basic cylinder of ; in. diameter and 6 in. stroke with the same total volume and the ıame clearance volume for all other proportions, will be considered. The expansion ratio may be 5 — that of the Clerk engine; the ›peed, 1200 r.p.m.; the piston speed will vary from case to case.

35 Using Formula [1] the conditions found are those recorded n Table 7.

36 The cooling loss increases regularly with increasing stroke-to-bore ratio. The absolute magnitude of the loss is small and the extreme variation changes the thermal efficiency by only 4 per cent. However, this 4 per cent means from 15 to 20 per cent saving in fuel. In an aeroplane 1 lb. of weight would be saved in fuel for a 10-hr. flight for every hp. of the engine output. This is not negligible, and will count more and more as longer and longer flights over sea, or over enemy territory, are attempted.

37 It might be thought that Table 7 does not really represent the situation, since it refers only to losses during the whole stroke. With full-out piston the surface-to-volume ratio may be less for large diameters and short strokes. The combustion space, however, will become more and more disk-shaped as the diameter increases its surface ratio will be great, and the losses during combustion considerable. However, as shown in Table 8, R for the clearance space varies but slightly in the opposite direction to R for the whole cylinder.

TABLE 8 VARIATION OF SURFACE-TO-VOLUME RATIO FOR CLEARANCE SPACE OF ENGINES IN TABLE 7

Stroke-to-bore ratio	1.0	1.2	1.4	1.6	1.8	2.0	2.5
R for clearance, sq. ft. per cu. ft.	18	17.7	17.3	17.2	17.1	17.0	17.0

38 *Influence of Varying Stroke-to-Bore Ratio Consequent on Varying Expansion Ratio.* The long stroke has in the popular mind become more or less associated with high thermal efficiency. The reason for this may be the high efficiency attained at a foreign test by certain motors having a remarkably long stroke. However, in these motors the long stroke was connected with a very high expansion ratio.

39 The next step is to investigate the influence of varying expansion ratio on engines of the same output and the same speed, the increase in expansion being brought about by lengthening the stroke. With increased compression and increased stroke the output per square inch of piston area will increase for the same number of revolutions. To obtain equal output the cylinder diameter will have to decrease with increased expansion ratio, as indicated in Table 9. In figuring the heat losses in this table it was necessary to use Formulæ [2] to [5], since the temperature conditions were no longer the same. The heat losses were obtained in heat units per pound of gas, not as percentages.

As Table 9 shows, while the cooling loss increases 18 per cent, icated work increases 61 per cent. The value of high expan- ven though gained by increased stroke-to-bore ratio and ed cylinder diameters, is hereby clearly demonstrated. For conditions, however, a high-expansion engine would be

E 9 INFLUENCE OF VARYING EXPANSION RATIO ON ENGINES OF THE SAME OUTPUT AND THE SAME SPEED

c expansion ratio	3	5	7	9
liameter, in.	5	4	3.5	3
	5	6	7	7.5
ke to bore	1	1.5	2	2.5
-volume ratio, R, sq. ft. per cu. ft.	13.3	15.5	16.7	19.0
ed, ft. per min.	1000	1200	1400	1500
erature, assumed, deg. fahr.	3270	3270	3270	3270
erature, assumed, deg. cent.	1800	1800	1800	1800
perature of expansion, deg. fahr.	2240	1850	1630	1470
perature of expansion, deg. cent.	1227	1007	887	802
B.t.u. per lb. of gas	100	103	108	118
cal. per kg. of gas	56	57	60	65
work, approx., B.t.u. per lb. of gas	188	248	278	303
work, approx., cal. per kg. of gas	104	138	154	168

ic exponent in computation of temperature drops, 1.3; compression work assumed equal ent of expansion work.

fficient with a large diameter and a short stroke than with a iameter and a long stroke.

Character of the Combustion in High-Speed Engines. In Table ooling losses and the indicated work are given in heat units it weight of gas. If to obtain percentages an attempt were

E 10 APPARENT SHAFT EFFICIENCIES FOR ENGINES IN TABLE 9

c expansion ratio	3	5	7	9
erature of compression, deg. fahr. abs.	1000	1170	1290	1390
erature of compression, deg. cent. abs.	556	648	718	773
ire rise to 3730 deg. fahr. abs.	2730	2560	2440	2340
ire rise to 2073 deg. cent. abs.	1517	1425	1355	1300
ired, approx. (C_v = 0.225), B.t.u. per lb. of gas.	615	576	550	525
ired, cal. per kg. of gas	342	320	305	292
mal efficiency from indicated work in Table 9, iff. 0.85)	0.26	0.365	0.43	0.49

o calculate the thermal efficiency of the engine by reference heat supplied during combustion, some very astonishing would result, such as those in Table 10. Here the maximum ature has been assumed equal to 3270 deg. fahr. (1800 deg. n all cases and the mechanical efficiency equal to 0.85.

42 It is evident that, even though 7 and 9 may be unusual expansion ratios in actual engines, we can never hope to attain brake efficiencies as high as those in Table 10. In arriving at these efficiencies no use has been made of the calculated cooling losses; we have simply taken a polytropic-expansion exponent equal to 1.3 and assumed that all heat is added before the expansion commences to take place. This is the way efficiencies are usually figured, although in combustion-engine practice the procedure is mostly veiled by the employment of mathematical efficiency formulæ, which have very little to do with actual processes.

TABLE 11 SHAFT EFFICIENCY AND COOLING LOSS OF ENGINE OF TABLE 9 WITH EXPANSION RATIO OF 5, ASSUMING ISOTHERMAL EXPANSION

	B.t.u. per lb.	Cal. per kg.
Isothermal expansion work (gas constant = 0.071)	385	214
Heat added between compression temperature (708 deg. fahr., 375 deg. cent.), and max. temp. (C_v = 0.225)	496	276
Cooling loss, estimated	162	90
Total heat supplied	1043	580
Compression work (exponent = 1.3)	104	58
Indicated work	281	156
Shaft efficiency (mech. eff. = 0.85)	0.229	0.22[illegible]
Cooling loss, per cent	15.5	15.5

43 Clerk in his paper before the Royal Society concludes from his experiments on an engine running at only 160 r.p.m. that some combustion is proceeding even during his first reëxpansion, i.e., after the whole normal expansion stroke and a whole intervening compression stroke. All experiments with closed vessels show gaseous explosions to take certainly not less than $\frac{1}{40}$ sec., and this only with over rich mixtures. With normal mixtures, it takes a much longer time than that to reach the maximum pressure. Turbulence accelerates combustion very much. Yet, such direct experiments as we have seem to show that with normal mixtures even a turbulent combustion would take all of $\frac{1}{40}$ sec. One-fortieth of a second, however, is exactly the time occupied by the whole expansion stroke of an engine running at 1200 r.p.m. We have then absolutely no reason to assume that the combustion is complete before the expansion commences. In the series of engines just considered it is far more reasonable to assume that it continues during the whole expansion stroke.

44 Assuming this we might approach the conditions actually obtaining by figuring with an isothermal expansion. During such

an expansion all the heat added passes directly into work. Assume a temperature of 1600 deg. cent. (2912 deg. fahr.) to obtain during the expansion, then with an expansion ratio of 5 we find for the corresponding engine in Table 9 the values given in Table 11.

45 The shaft efficiency is now about what would be expected from an engine of this size and speed, and the cooling loss is considerably increased. The main reason for the lowered efficiency, however, is not cooling loss, but delayed combustion. To increase efficiency in explosion engines running at very high speeds the main prerequisites are extremely efficient carburation, extremely efficient ignition, and *perhaps*, if feasible, some means for increasing the turbulence during combustion.

46 It would hardly be good practice to increase turbulence by means of greater gas velocities and greater throttling losses in valves. The writer knows of an engine in which very complete combustion is secured by forcing the mixture through narrow grooves in the working piston. The design, however, involves an auxiliary piston driven by an auxiliary linkage, and it is possible that two inlet valves with "clashing" currents might prove of some value. Here a considerable field for invention is yet open.

47 In concluding this paper, the writer wishes to express his deeply felt gratitude to Prof. William T. Magruder, Mem.Am.Soc. M.E., who in the midst of extremely arduous war duties has not grudged the writer encouragement and advice.

DISCUSSION

Wm. T. Magruder (written). Assuming the correctness of Equation [1], of Par. 19, let

s = stroke in inches
c = stroke / diameter
N = r.p.m.
$V = 2sN$ = piston speed
K = ratio of total volume to piston displacement.

Then

$$R = \frac{\text{surface}}{\text{volume}} = \frac{\frac{2\pi d^2}{4} + K \times \pi d \times cd}{\frac{\pi d^2}{4} \times Ks} = \frac{2 + 4cK}{sK}.$$

Substituting in Equation [1],

$$L = L_0 \frac{\dfrac{2 + 4\,cK}{sK}}{\dfrac{2 + 4\,c_0K_0}{s_0K_0}} \times \frac{N_0}{N} \times \left(\frac{2\,sN}{2\,s_0N_0}\right)^{0.5} = L_0 \frac{\dfrac{2 + 4\,cK}{K}}{\dfrac{2 + 4\,c_0K_0}{K_0}} \times \left(\frac{V_0}{V}\right)^{0.5}$$

If we assume that the two engines have the same clearances and the same compression ratios and that $K = K_0$, and that they have the same ratio of stroke to diameter and that $c = c_0$, then Equation [1] reduces to

$$L = L_0 \left(\frac{V_0}{V}\right)^{0.5}$$

in B.t.u. per unit weight of gas used; that is, that for the same ratio of stroke to diameter and the same compression ratio in the two engine cylinders, and for equal weights of gas used, the loss is inversely proportional to the square root of the ratio of the piston speeds.

Attention should be called to the leanness of the mixture which formed the burnt gases given in Par. 11 and to the low average temperature of the wall surrounding the combustion space.

The fallacy of the hypothetical assumption made in Par. 42 is shown by the continuity of the combustion during the stroke as is shown by the continuity of the flame during the stroke and after the opening of the auxiliary exhaust port, and also by the temperature of the gases in the cylinder as measured by the electric pyrometer.

With reference to the drop in temperature in the exhaust port and pipe, it is well known to experimenters that the drop is very rapid and apparently much more rapid in most commercial engines than the figures given for the engine experimented with by Professor Coker would indicate.

As to the heat given to the exhaust passages of an engine, the results of a number of runs made with the 14-in. by 18-in. single-acting tandem Buckeye gas engine, using natural gas, in the Mechanical Engineering Laboratory of The Ohio State University, show that with total jacket-water losses ranging from 24.9 to 35.6 per cent, depending on the load, at full load 38 per cent went to the cylinder barrels, 22.9 per cent to the cylinder heads, 20.6 per cent to the pistons, 13.7 per cent to the exhaust-valve seat and boxes, and only 4.9 per cent to the exhaust valves and their stems.

Louis Illmer (written). The opening statement of the paper that a great part of the heat loss in an internal-combustion engine

orbed by the exhaust passage, is not borne out by my research es in Heat Flow Through Cylinder Walls as presented before ociety of Automotive Engineers (see *S.A.E. Journal*, January . It can be shown that the major portion of the heat loss properly adjusted moderate-speed explosive engine is given off e cylinder and head jacket walls during the early portion of xpansion stroke.

would further point out that my investigation presented a r explicit method of procedure from which the heat-flow char- istics of any normal gas or oil engine can be quantitatively termined with sufficient accuracy to meet all commercial de- requirements.

y conclusions, as based upon jacket-loss analysis of a consid- e number of engines, are at variance with the statements made e paper under discussion. My own findings are that heat through jacketed cylinder walls is controlled by three principal rs as expressed by the following formula:

$$H = C_f \left(\frac{p_m}{E}\right)^{\frac{4}{3}} \frac{N}{\log N} F^{\frac{2}{3}}$$

e H = uniformly distributed full-load heat flow through the jacketed cylinder wall as measured in B.t.u. per hour per sq. in. of effective cooling surface A_e

C_f = constant depending upon the cycle of the engine
= 0.001 for four-stroke cycle engines
= 0.0016 for two-stroke cycle engines

p_m = mean effective pressure, lb. per sq. in.

E = thermal efficiency as indicated in the power cylinder.

N = engine speed in r.p.m.

F = surface factor, that is, effective volume V_e in cu. in. divided by the effective surface A_e in sq. in., as measured with the piston standing at $\frac{1}{4}$ stroke from its inner dead-center position.

he first factor, p_m/E, of this equation measures the temperature ccurring during the explosion period and is shown to be approxi- ly proportional to the average temperature head driving the from the hot gases into the cylinder wall.

he second factor, $N/\log N$, is the time factor. For speeds below o 250 r.p.m. the law of change of heat flow with speed does not rially differ from that taken upon the $\sqrt{N}$ basis, while at higher

speed this ratio as used by the author leads to an excessive rate of heat loss.

The last factor, F, is a surface factor. To arrive at a consistent value for the equivalent effective cooling surface in an explosive gas engine, a certain portion of the bore surface must be added to that of the clearance space.

According to the formula given above, the influence of the surface factor should not be taken directly proportional to F but rather as a function of F^n.

Heat flow in high-speed internal-combustion engines is a complex phenomenon and it does not appear that very satisfactory practical conclusions as regards the best stroke-to-bore ratio can be deduced from experiments with intermittent explosions in a closed vessel, since these lack the all-important element of changing surfaces and the repeated temperature applications due to the reciprocating piston movement.

Furthermore, as is quite fully shown in my paper on Heat-Flow, the temperature assumed by the cylinder bore of an engine is an extremely important matter to the designer in fixing the limiting engine speed. In case certain very definite bore temperatures are exceeded, piston lubricating troubles will be sure to follow.

When working in an uncertain domain of this kind, my research experience has led to the conclusion that a study of speed limitations in existing engines offers a far more promising basis for determining the rate and effect of heat flow through cylinder walls than does the author's method, which relies upon a series of disputable assumptions which may or may not accord with practice.

It is thought, therefore, that reliable data regarding the laws of heat flow can, for the present at least, be most readily deduced from a research study of conditions identical with those met with in the actual operation of gas and oil engines. After the laws underlying heat flow are firmly established and thoroughly understood, their application to scientific engine design is a relatively simple matter.

O. C. Berry [1] (written). I am pleased to see that the paper calls attention to the common error of considering that a larger engine should be more efficient than a smaller one. I do not agree, however, with the conclusions drawn relative to the influence on the efficiency of an engine of changing its stroke-to-bore ratio.

[1] Associate Professor of Gas and Automotive Engineering, Purdue University, Lafayette, Ind.

The rate of flow of heat from the hot gases to the walls per degree of temperature difference per square inch of surface per second is considerably greater at high than at low gas temperatures. The combustion chamber, piston head and a comparatively small part of the head end of the cylinder walls are the only parts exposed to the highest temperature of the explosion. The crank end of the cylinder is exposed only for very short periods of time and then to comparatively low gas temperatures. It is therefore perfectly obvious that the cylinder walls will not absorb as much heat per square inch of surface as will the combustion chamber.

Considerable work has been done in determining the cyclical changes of temperature in a gas-engine cylinder by such men as Dugald Clerk, Professors Burstall, Hopkinson, Coker, Dalby, and others. From their results it is possible to figure fairly accurately the comparative amount of heat that will be absorbed by any part of the cylinder walls. It will be found that on the average 1 sq. in. of cylinder wall will absorb not more than one-third as much heat as one 1 sq. in. of combustion-chamber surface. The total effective cooling surface in an engine may therefore be expressed in terms of equivalent square inches of combustion-chamber wall by adding one-third of the cylinder-wall area to the area of the combustion chamber. The total heat absorbed by the jackets should vary in exact proportion to this equivalent cooling surface, all other factors being equal.

Referring to Equation [1], Par. 19, I feel, therefore, that the cylinder walls should not be treated as the exact equivalent of an equal area of combustion-chamber walls. The equation is also based upon the assumption that the coefficient of heat transfer from the gases will vary as the square root of the piston speed. Probably only a small portion of the gases ever comes in contact with the cylinder walls, and the flow of heat to the combustion-chamber walls will not be affected at all by the piston speed, as distinguished from the revolutions per minute. This item should therefore be eliminated entirely.

The inertia forces increase as the square of the engine speed. For this and other reasons the percentage of power lost in friction increases as the speed increases. At very high speeds it is difficult to obtain a combustion that is rapid enough to give the best efficiency. At the higher speeds it is hard to obtain a high volumetric efficiency. All of these factors tend to modify the efficiency obtainable in a high-speed engine and the temperature conditions under which it

works. Except as modified by these and like causes, the heat loss will vary directly as the square inches of *equivalent* cooling surface. This may be expressed in the form of an equation that will take the place of Equation [1] as given by the author.

Let L_0 = calories jacket loss per pound of a given fuel, P = pounds of fuel used per minute, and S = equivalent cooling surface, sq. in. Then

$$L = L_0 \times \frac{S}{S_0} \times \frac{P_0}{P}.$$

This relation will have almost no bearing upon the stroke-to-bore ratio.

Applying this idea to the seven engines of equal cylinder volume and varying stroke-to-bore ratios referred to in Table 7, the results will be as given in Table 12. This shows that, within these limits,

TABLE 12 ENGINES WITH EQUAL VOLUMES BUT VARYING STROKE-TO-BORE RATIOS

Ratio, stroke to bore	1	1.2	1.4	1.6	1.8	2.0	2.5
Diameter, in.	5.3	5.0	4.74	4.53	4.35	4.2	3.9
Stroke, in.	5.3	6.0	6.63	7.25	7.81	8.4	9.75
Combustion-chamber surface, sq. in.	66.2	62.8	60.0	58.0	56.4	55.4	53.8
Cylinder-wall area, sq. in.	88.2	94.2	98.6	103.0	106.8	110.8	119.6
Equivalent cooling surface, sq. in.	95.6	94.2	92.8	90.1	92.0	92.3	93.6

changing the stroke-to-bore ratio has very little effect upon the jacket losses. A ratio of about 1.6 is the very best from this point of view, in so far as there is any choice at all. This will be found to correspond to actual experience. Well-designed engines of similar size and speed, having the same compression ratio and using the same fuel, will not be found to vary in efficiency or in the percentage of heat lost in the cooling water according to their stroke-to-bore ratio. The choice of this ratio is governed entirely by other considerations.

H. M. CRANE[1] (written). Most of the experimental work of the Simplex Automobile Company and the Wright-Martin Aircraft Corporation has been done on engines of relatively high speed. I have had the feeling that in engines of this kind, where rapid development is necessary, that an attempt to determine the distribution of heat losses is practically out of the question, and that the best results can be obtained by experimenting almost entirely in overall efficiency.

[1] Vice-President, Wright-Martin Aircraft Corporation, New Brunswick, N. J.

The paper does not go into the difficulties of multi-cylinder engine construction, which are of course of the greatest possible importance, the reason being that to secure large power with light weight the best results have been so far obtained with at least six cylinders and usually a still greater number. Where a considerable number of cylinders are used, the question of loss of heat to the cylinder walls is not usually as difficult as that of supplying an absolutely uniform mixture of air and fuel to each cylinder. It is obvious that if this is not done, no really high efficiency can be expected, as only part of the cylinders can then operate at maximum efficiency. The results of our development work have indicated that engines of moderate proportions can be expected to give the best all-round results, and that extremes in cylinder sizes, in stroke-to-bore ratio and in valve timing are apt to result in greater weight and reduced efficiency of operation. This seems to confirm the author's conclusions.

We have obtained interesting comparative results between our two types of 8-cylinder aviation engines, the smaller being of 120 mm. bore and 130 mm. stroke, and the larger of 140 mm. bore and 150 mm. stroke. The larger engine has always shown a slightly higher mean effective pressure than the smaller engine, but has never been able to equal the low gasoline consumption of the smaller engine. The smaller engine also can be operated at somewhat higher temperatures, although it still develops its high efficiency at as low temperatures as those under which the larger engine is operated. It would then appear the smaller engine is obtaining its efficiency with a probably greater proportionate loss of heat to the cylinder walls. The explanation would seem to be then that the difference is due to reduced efficiency of combustion in the larger engine and results from variations of the mixture in different cylinders or a less complete mingling of air and fuel.

Lawford H. Fry (written). The author offers a formula for the loss of heat by gas in the cylinder of an internal-combustion engine which is attractive by reason of its simplicity, but until further experimental evidence is offered there must be considerable doubt as to whether a formula of so simple a character can express accurately the complex process involved.

In a study of the loss of heat by a gas flowing through a flue, presented to the Society last year (Trans. Am.Soc.M.E., vol. 39, p. 709), the present writer showed that the amount of heat given up

by the gas in its passage through the tube depended on the following factors:

1 Initial temperature of the gas
2 Temperature of the flue wall
3 Mean hydraulic depth of the flue
4 Time that each particle of gas takes to pass through the flue
5 Weight of gas passed over each square foot of tube surface.

It appeared that the linear speed of the gas does not have the effect, often ascribed to it, of accelerating heat transfer by increasing the rubbing or scrubbing action of the gas on the flue wall. The linear speed has a controlling influence on the rate of heat transfer but this influence is due to the fact that factors 4 and 5 depend on the speed of gas flow. The rate of flow in a given flue determines the time that each particle of gas remains in the flue and also the number of particles of gas which pass over each unit of area of the flue surface.

Now if linear gas speed per se does not affect the rate of transfer, there is a great similarity between heat transfer from a flowing gas and heat transfer from gas in a closed vessel. By analogy with the flowing gas it would be expected that the enclosed gas would have the rate of heat transfer determined by the following factors:

1 Initial temperature of gas
2 Temperature of cylinder wall
3 Mean hydraulic depth of cylinder, i.e., volume divided by surface
4 Time gas is enclosed in cylinder
5 Weight of gas per unit of cylinder surface.

The author's formula includes these factors but combines them in simple powers, while the flowing-gas formula shows that an elaborate exponential relation exists between them. It is thought that the examination of further experimental data as such becomes available will show the necessity for a more elaborate formula for the enclosed gas. For example, take the author's assumption that the amount of heat transferred from gas to cylinder is directly proportional to the time of stroke, that is, to the time the gas is in contact. This is obviously incorrect. The rate of cooling is dependent on the temperature difference between gas and cylinder wall. As contact between gas and cylinder continues the temperature difference decreases and consequently the rate of transfer decreases. It follows that in each succeeding instant of time less and less heat will

be given up by the gas. The relation between time of contact and amount of heat transferred must be expressed by an exponential function.

It is hoped that the author's work may be the beginning of some investigations of heat transfer from enclosed gas which can be tied in with the work already done on heat transfer from flowing gas. It will, however, be necessary to have a very much larger body of experimental data, and a more searching analysis of the controlling factors of the process.

E. R. Hedrick (written). The profound influence of this paper upon design is sufficiently evident to suggest that even greater accuracy might be attempted. Thus, the author himself suggests that two of the assumptions are only approximate. That the temperature loss is proportional to the surface-to-volume ratio is a reasonable assumption, but further experiments might well be undertaken to establish this point. Thus, a superficial examination might tend to lead us to subtract from the surface half the cylinder surface passed over by the piston; but it is not at all clear that this would be correct, since the entire cylinder is exposed to heating so frequently that the dissipation of heat may be practically as great as if the cylinder were constantly full. It is to be remarked, however, that the temperature is greatest when the exposed surface is least. Hence any refinement must wait upon further experiment.

The same is true of the assumption that the coefficient of heat transfer is proportional to the square root of the rubbing velocity. One suggestion might be that the surface-to-volume ratio can be expressed simply in terms of the stroke-to-bore ratio: it might turn out that a very simple relation exists between the heat loss and this ratio, at least if the clearance is constant.

The Author. It is a source of gratification that the paper has called forth comments from a number of men so well qualified to deal with the subject. An immense amount of experimental work is being done in this country, but unfortunately, very little of it ever becomes accessible to the profession at large; and a very great deal of it is never properly analyzed or criticized.

The cooling losses in a combustion engine are physically a very complex phenomenon to deal with quantitatively and the task of expressing them by a formula readily manageable by practical designers is a difficult one. The author has tried to avoid a few of the

omplexities by the introduction of a variable factor, C, in Formula 8], based entirely on experimental data from the most careful tests with which he is acquainted — those of Dugald Clerk. Clerk gives the cooling loss in his engine expressed as equivalent temperature drop during the whole expansion stroke, plotted against mean temperature during the stroke. The factor C is simply the equivalent temperature drop transformed into B.t.u. per pound of gas. This C, then, contains and allows automatically for —

1 The temperature variation during the stroke
2 The volume variation during the stroke
3 Differences in temperature of combustion and expansion, at least for conditions not differing too much from those of the experimental engine.

For conditions differing widely, for instance, with regard to compression ratio or with regard to rapidity of combustion, considerable errors in C may occur. The question is, Would it be possible to evolve any manageable formula, give any set of practical constants, where the same would not be true? The author feels that very much additional experimentation is necessary, especially with regard to kerosene engines and high-speed engines generally. His own deliberations on this part of the subject he considers merely as a more or less plausible guess.

While it is true that the major part of the cooling losses occur at the beginning of the stroke, it is not true as a general proposition that the jacket losses in the exhaust passages are not worthy of being corrected for. In the case of the Clerk experimental engine they were 36 per cent of the total loss; in the Buckeye engine mentioned by Professor Magruder, 18.6 per cent; in an engine examined by Gibson and Walker, from 8 to 12.5 per cent. *À priori* there is every reason to assume that they are high in high-speed engines with greatly delayed combustion. These losses do not occur during the working stroke and should not be subtracted from the figured expansion work of the engine. If efficiency is estimated simply from overall heat balances, then it makes no difference whether this part of the jacket loss is charged as exhaust loss or as jacket loss. In analyzing what happens during the expansion stroke, however, this loss must not be charged as energy disappearing into the cylinder walls.

Putting cooling loss proportional to the square root of the piston speed was, to begin with, simply done "for luck." It was designed

to express certain general practical experiences, as well as the general effect of turbulence.

The close agreement between the losses as figured by the formula and those indicated for the experimental engines of the Institute of Civil Engineers seemed, *post factum*, to furnish a good justification for the assumptions made.

An allowance for differences in pressure, as distinct from differences in expansion ratio, would no doubt be a refinement. The difference in expansion ratio, as it is, makes itself felt solely through the mean temperature during the stroke, and thence through the factor C, as read from the curve in Fig. 3.

In engineering work, simplicity, ease of orientation, is often more important than exactness. Fully appreciating the weight of the criticism offered, the author sees no reason why his formula should not be used with some confidence, at least for engines not too dissimilar from Clerk's.

For multi-cylinder engines he realizes keenly that a much more searching investigation is desirable. Personally he would like nothing better than to attack the problems mentioned by Mr. H. M. Crane. To some extent he has done so in a paper published in *Automotive Industries*, February 27, 1919.

No. 1664

THE WEIGHTS AND MEASURES OF LATIN AMERICA

By Frederick A. Halsey, New York
Member of the Society

"I have found in the course of my life that the particular thing that you have to surrender to is the facts."
— President Wilson.

THE inquiry of which this paper is a report was conducted through a questionnaire of which about 500 copies were distributed throughout South and Central America and the West Indies.[1] In order to secure representative and impartial distribution, outside agencies were enlisted in the work, the printed blanks being sent to their branches and correspondents by the National City Bank, the United Fruit Company, W. R. Grace and Company, and the Hill Publishing Company. Additional copies were sent out by the author to names taken from a commercial list obtained from the United Fruit Company and to United States consuls.

2 The actual printed forms sent out were translated into Spanish and Portuguese, in which languages most of the replies came back. The information given herein is not, however, limited to that obtained through the questionnaires as various citations in the text point out. In all cases quotations without names attached are from the questionnaires.

SPANISH AND PORTUGUESE WEIGHTS AND MEASURES

3 As many readers are not acquainted with Spanish weights and measures, tables of the more common units and their relations

[1] This paper embodies the results of an investigation conducted under the auspices of the American Institute of Weights and Measures, of which the author is the Commissioner.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers. For discussion, see Mechanical Engineering, January, 1919.

are here given. The translation of the Spanish names is almost self-apparent, but the following are given:

Onza	Ounce	Pulgada	Inch
Libra	Pound	Pie	Foot
Tonelada	Ton	Vara	Yard
Cuartillo	Quart		

4 The Portuguese names are so similar that their meanings will be apparent.

SPANISH WEIGHTS AND MEASURES

WEIGHT

16 onzas	= 1 libra
25 libras	= 1 arroba
4 arrobas	= 1 quintal
20 quintales	= 1 tonelada

DRY MEASURE

4 cuartillos	= 1 celemin
12 celemins	= 1 fanega
12 fanegas	= 1 cahiz

LIQUID MEASURE

4 cuartillos	= 1 azumbre
8 azumbres	= 1 cantara
16 cantaras	= 1 moyo

LENGTH

12 pulgadas	= 1 pie
3 pies	= 1 vara

UNIFICATION OF ENGLISH AND SPANISH WEIGHTS AND MEASURES

5 With slight differences in the values of the units, this system is substantially identical with our own. With suitable foresight and effort the two might have been unified long ago.

6 The chief difficulty in the adoption of the metric system in Latin America has been and is the psychological difficulty — that is, learning to think or visualize values in strange units. In this sense the difficulty of adopting the English values of the units would have been nil for there would have been too little change in values to cause confusion of thought, while in names there would have been none.

7 Meanwhile the still greater difficulty in our own case — the physical difficulty due to the anchorage of units in standardized manufacture — was and is absent in Latin America where but little manufacturing is done. The difficulties in the way of adopting the English values of the units thus were and are trifling in comparison

with those in the way of adopting the metric units. Moreover, the process would have been one of subtraction, two sets of values being reduced to one, and, internationally considered, several sets of values reduced to one, for the Spanish units have slight and annoying differences of value in different countries. The "adoption" of the metric system, on the other hand, has been one of addition, another set of units being added to those already existing.

8 The ease with which the English values of the units might have been adopted is shown by these reports of the progress they have made. With no trace of compulsion or even governmental recognition, they have come into large use by the operation of the forces of trade and commerce and by simple acceptance, whereas the metric units have nowhere made progress except by compulsion.

9 The remaining question is: Is it too late? Except for units for land measure, which, once established, should be let alone, I think not, for conditions have not materially changed in Latin America. It must be apparent there, as this inquiry makes it here, that the attempt to adopt the metric system is a failure. The weights and measures of Latin America are in a state of chaos, for which a remedy is sorely needed. Were they to dismiss the intruder and retain the old historic names with changes in values which are so slight as to be inappreciable for most purposes, Pan-Americanism in this important field would become an accomplished fact, and the unification of the weights and measures of North and South America with those of the British Empire would be within sight.

10 It is especially to be noted that until about the beginning of the present century there were few, if any, compulsory metric laws in Spanish America. The system had been "adopted" in many of those countries as the official system, and used chiefly for customs purposes and railway tariffs, but the people continued to use the old measures without molestation. The change in the intervening years is due to German influence and for German purposes. If, as seems probable, German influence in Spanish America is to suffer an eclipse, is it too much to hope that the future may see the unification of the weights and measures of North and South America and the British Empire on the foundation of the system which, in its basic and historic features, is common to all?

11 Meanwhile we have an important lesson to learn from Latin America. A glance through these reports will reveal the common practice of selling grain and other farm products at wholesale by *weight*, the arroba and the quintal being favorite units.

12 Our clumsy efforts to connect the bushel and pound through conversion factors are the cause of much confusion[1] which would disappear were we to copy this practice, and, incidentally, deprive the metricites of a false argument which is on all their lips, and which the unthinking know no better than to accept. The unit for this purpose should be the quintal of 100 lb. — a name which is preferable to hundredweight as it avoids confusion with the British hundredweight of 112 lb.

GENERAL ANALYSIS OF RESULTS

13 The effort to learn the relative usage of the different systems has not been successful. When one return gives exclusive use of the metric system for a given purpose and another exclusive use of the Spanish system for the same purpose, discrimination is impossible. The thing here proven is that the claim that Latin America is metric is false, as are all arguments based upon it. In particular, it should be noted that the order in which the units are herein named has no significance.

14 In but one of the countries investigated (Uruguay, which see below) can the metric system be said to be adopted for domestic trade, while there we find an authorized official exception in the case of real estate, as we find other exceptions in the cases of wearing apparel, industry and navigation. Nevertheless, in twelve of these twenty countries, according to the Director of the Bureau of Standards, the metric system is "obligatory."[2]

15 In ten of these countries (apart from the railroads and other fields under immediate government control) the metric system has made very little impression. (Nicaragua, Guatemala, Spanish Honduras, Cuba, Panama, Colombia, Porto Rico,[3] San Salvador, Ecuador, and Costa Rica, which see below.)

[1] It should be noted that the adoption of the metric system would not do away with this confusion since wheat, corn, rye, etc. do not weigh the same per decaliter any more than they do per bushel. The sale of these and similar commodities by *weight* is the simple and sufficient method of abolishing all the confusion now experienced in this branch of trade.

[2] See The Metric System in Export Trade by the Director of the Bureau of Standards, page 17; Senate Document No. 241, Government Printing Office, 1916.

[3] Porto Rico is always claimed by the metricites to be metric. Thus, according to Mr. Fred R. Drake, Chairman Executive Committee, American Metric Association, "The meter, liter and gram continue to prove most satisfactory in official and general use in the Philippine Islands, *Porto Rico* and other United States possessions."

16 Of these ten countries, according to the above report, the metric system is "obligatory" in seven. In five of them (Cuba, Colombia, Porto Rico, Panama, and Spanish Honduras, which see below) the English units are used far more than the metric, having largely supplanted all others, although in three of them, according to the report mentioned, the metric system is "obligatory." Not only has the English pound come into large use, but the arroba and quintal have been adjusted in value to make them equal to 25 and 100 English pounds, respectively. In substantially all of the countries investigated the English inch is used for mechanical purposes, as the English nautical units are used for navigation and sea shipments. That most derided of English units — the nautical mile — is used by all countries that sail the seas and they use no other. The kilometer is an unknown measure at sea.

17 In all countries the impression made is in direct relation to the severity of the laws, of which we have the climax in Uruguay (see Uruguay below), with Venezuela and Argentina not far behind. In all cases the movement was begun with mild laws under the impression that the adoption of the system was a simple and easy thing to bring about. Such laws failing, more drastic ones followed, but even these have been but partially effective. The greatest progress has been made in the field of domestic retail trade, in which weights and measures are under the immediate eye of officers of the law.

18 It is this field which comes under the observation of tourists. One may tour through, or, for that matter, live in a country for many years, in many walks of life, and experience but little contact with weights and measures outside the field of retail trade, and we thus see why the reports of tourists are more favorable to the metric system than the facts justify, as we also see why the observations of tourists, in a comprehensive sense, have very limited value.

19 The further we get from the field of retail trade, the less is the system used. In this field the progress is chiefly with units of weight and capacity, the measure of length for the sale of drygoods being commonly the vara, while imported wearing apparel of all kinds is commonly sold by the units of the country of its origin, by the inch at least as much as the centimeter, and domestic products are frequently made to numbered sizes, of which the relation to any system of units is not apparent. They are not metric.

20 In primary or wholesale markets the old measures prevail,

although these, in some cases, have been adjusted in value to make them even multiples of English basic units. We have here perfect examples of the simple process of unification of English and Spanish measures which, with proper encouragement, might by this time have become substantially universal.

21 Lumber and timber are almost universally sawn to the inch, although frequently mixed with the vara or the meter for length, and the square and cubic meter as sales units, prices being made at so much per square or cubic meter for one-inch boards.

22 In the mechanical trades tailors and seamstresses use all three systems, as do stone and brick masons, while carpenters commonly use the pulgada or inch. In machine shops both English and metric units are used, depending chiefly on the country of origin of the machines they have to repair. The inch is predominant.

23 In this connection we have the report of the Cleveland Twist Drill Company that shipments of their tools to South America are "95 per cent to 100 per cent English," and of the Detroit Twist Drill Company that "All of our South American customers use more English sizes than metric." Needless to say, English-sized twist drills are bought in order to make English-sized holes, for they will make no other.

24 In ship and boat building, also, the English units find large use, while in mining and smelting we find a miscellaneous mixture of all three systems.

25 The persistence of old units is most pronounced in the measurement of land. When units of measure are once anchored in titles to real estate, they are there to stay. Of this we have perfect examples in the use of the French arpent in Louisiana and the Spanish vara in Texas, in which states those units are today the common units of land measure. Another example is found in France, where, in some sections, the old units of land measure are still predominant.

26 When outlying districts are incorporated within city limits, parcels of land are much reduced in size and smaller units come in. This gives an opportunity for the introduction of the metric system, but with the result that, in the older portions of the town, the old units are used, while in the newer portions we find the new ones.

27 Similarly, initial surveys of the *hinterland* give an opportunity for the use of new units, but again with the result that the

older portions of the country are measured in one set of units and the newer in another.

28 In Uruguay, where the laws are more severe and more rigidly enforced than in any other country, it has been found necessary to authorize the use of old units for the measurement of land (see Uruguay below), while in other countries the laws, in this application, are quietly ignored. This is the more significant because all transfers of real estate, as matters of public record, come before the eyes of officers of the law. In other countries, again, the purchase and sale are made in Spanish units and the day is then saved by inserting metric equivalents in the documents of record.

29 In marine measurements and sea shipments the English system is used everywhere, although mixed with metric units, especially for inland navigation.

30 Classified in another way, the most-used metric units are those of capacity. Next come those of weight, and, trailing far in the rear, those of length and their correlatives of area. This is in accordance with a law which long ago made itself apparent.

THEORIES DISPROVEN

31 On its face this Report sets forth a volume of facts regarding the weights and measures of Latin America, but, in addition to this, it disproves many theories.

32 The first theory is that it is an easy and simple matter for a country to change its system of weights and measures. Here we have the results of twenty attempts to bring about this change, most of which date from about the middle of the last century. With but one exception the result has been grotesque failure, while in none has the attempt to retire old units been successful.

33 It is on this theory that the entire metric case is based. Once one has accepted the idea that a country may easily change its weights and measures, it is a short step to the conclusion that those who have tried it have succeeded, and then another short step to the conclusion that we can succeed. The question at issue is one not of belief but of fact. With twenty failures after, in most cases, more than a half century of effort, the fact is proven.

34 The second theory is that the adoption of the metric system does away with confusion of weights and measures. These reports show that the actual result is to increase and not eliminate confusion.

35 The third theory is that the metric system is in universal use, except in the United States, the British Empire and Russia. These reports show that in no country investigated is the system universal.

36 The fourth theory is that we must adopt the metric system if we are to succeed in selling goods to Spanish America. These reports show that if we are to change our weights and measures in order to conform to the practice of Spanish America, we should adopt the Spanish and not the metric system.

37 The fifth theory is that the "adoption" of the metric system leads to an important saving of time in primary education. Clearly, with a mixture of systems in use, children have more and not less to learn.

38 The sixth theory is that the adoption of the metric system leads to a saving of time in calculations. Clearly, with this mixture of systems in use, involving the constant necessity for conversions between them, the labor of calculations is increased and not reduced. For example, consider the purchase at wholesale by the meter and the sale at retail by the vara.

39 The seventh theory is that the persistence of old units in metric countries is a persistence of names but not of things — that the practice is nothing more than the use of old names for new units. One of the most recent formal statements of this theory is by Dr. William C. Wells, Chief Statistician of the Pan-American Union, who says (*Bulletin* of the Pan-American Union, January 1917):

> It has been found somewhat difficult in countries adopting the metric scale to do away with the names of the most-used measures such as yards, quarts, pounds, miles etc., or rather of the equivalents of those English words in the language of the country adopting the metric system. . . . It has been found very easy to substitute the thing, although sometimes difficult to substitute the word. . . . Scarcely a vestige of the old system is left in any country that adopted the metric system. Now and then in Latin-American countries one will hear the old words, but almost always with a meaning adapted to the new scale.

40 These replies are sprinkled with such expressions as these:

> "Same as in the United States." "English sizes." "For distance, the English mile." "English and metric system." "French and American indiscriminately." "Thickness of lumber is always in English inches." "Metric system infrequently." "The two standards are used indiscriminately." "The meter is used very little." "The artisans of the country use in their calculations the Spanish vara as their standard." "Our standard of weight is the quintal of 100 Spanish pounds." "The people continue to use the old Spanish measures." "At retail, vara; at wholesale, yard, meter." "While the metric system is legal

it is not enforced." "In domestic business, only the Spanish system is used." "A few French articles are in metric sizes." "The cuadra is still commonly used, but is prohibited in the documents." "The English measures prevail." "Generally the English foot, exceptionally the meter." "The old Brazilian system is still commonly used." "Cloths are sold indiscriminately by meters, varas and yards." "Occasionally the metric ton." "The metric measurements are sometimes used."

Such expressions as the above, of which there are many more, cannot be thus explained.

41 Many of these reports *give values of the Spanish in terms of metric and English units* which show that the old names are not used for the new units. Of these, a few of many examples follow (note that the libra is *not* a half-kilogram):

From Costa Rica: Vara, 0.836 meter; libra, 460 grams; cuartillo, 4.165 liters; botella, 0.67 liter; manzana, 6988 square meters.

From Argentina: Vara, 0.866 meter; pie, 0.289 meter; libra, 0.4594 kilogram; tonelada, 918.8 kilograms.

From Nicaragua: Vara, 33 inches; libra, 16 onzas; fanega, 288 libras; manzana, 10,000 square varas.

From Ecuador: Vara, 84 centimeters; libra, 16 onzas; cuadra, 100 square varas.

From Guatemala: Vara, 2.78 feet; manzana, 10,000 square varas; caballeria, 64 manzanas; cuadra, 625 square varas.

From Mexico: Vara, 2.7 feet; onza, 1.0148 ounces avoirdupois; cuartillo, 1.7 quarts; sitio, 1755 hectares; caballeria, 42 hectares.

From Venezuela: Vara, 0.836 meter; pie, 0.279 meter; pulgada, 0.023 meter; libra, 460 grams; arroba, 11.5 kilograms.

From Honduras: Vara "about 33 inches"; manzana, "100 square English yards."

From Brazil: Libra, 0.45905 kilogram; arroba, 14.6896 kilograms; oitava, 3.586 grams; quartilho, 0.665 liter; canada, 2.662 liters.

From Peru: Vara, 83 centimeters; topo, 5000 square varas, or 3485 square meters; quintal, 46 kilograms; marco, 228 grams.

From Chile: Quintal, 46 kilograms; arroba, 11½ kilograms; corcada (cord for firewood), 6 pies × 3 pies × 3 pies.

42 More might be given to the point of weariness, but the above are sufficient. Not one of all of these hundreds of sheets contains a single item to substantiate the theory advanced by Dr. Wells. No proof of it has ever been offered; it is clearly untenable and must be dismissed.

43 The eighth theory is that we will use metric equivalents for English sizes, or, as the metric party puts it, "Whatever is manufactured must be actually the same size or weight as before. It is merely a matter of a new term of expression." Nothing to justify

this theory can be found in these papers, no single example of this practice being found therein. Articles manufactured to the inch (wearing apparel, pipe, lumber, etc.) are uniformly sold by the unit to which they were made.

THE RESULT OF A GREAT SERIES OF EXPERIMENTS

44 We have in this Report a composite picture of the result of many attempts to adopt the metric system, that result being uniformly the addition of that system to those previously prevailing, and it is this that we must contemplate as the result of the attempt to adopt it here. We must compare what we have with what we will get, not with what one may hope we will get. Moreover, it must be noted that had all these countries succeeded in this great experiment, it would have no significance for our guidance, because of the greater importance of our manufacturing industries. France adopted the system before the beginning of the manufacturing era, and Germany adopted it before the development of manufacturing in that country. Everyone knows that the rise of Germany as a manufacturing nation began after the war of 1870. South American countries are not manufacturing countries. More manufacturing is done in the city of Philadelphia than in all South America.

45 We see then that in western Europe the system was adopted before the development of manufacturing and that manufacturing has developed with and in it, while in South America practically no manufacturing is carried on.

46 Great Britain and we are the first to be asked to change our manufacturing units, for which there is not a shadow of a precedent.

47 Seldom has an effort of such magnitude been made. We have here a record of twenty experiments on a national or, collectively, a continental, scale, and their net result is to demonstrate the wisdom of the conclusion arrived at by John Quincy Adams after four years of investigation and nearly a century ago:

> The substitution of an entire new system of weight and measures instead of one long established and in general use, is one of the most arduous exercises of legislative authority. There is, indeed, no difficulty in enacting and promulgating the law, but the difficulties of carrying it into execution are always great and have often proved insuperable.
>
> The legislator . . . finishes by increasing the diversities which it was his intention to abolish, and by loading his statute books only with the impotence of authority and the uniformity of confusion.

It is to protect our country from this "uniformity of confusion" that we are fighting.

THE RESULTS ARE NOT SURPRISING

48 Some who read this Report will, no doubt, be surprised at the condition disclosed in Spanish and Portuguese America, but there is no reason why any one should be surprised as no one has seen the first scintilla of proof to the contrary. Assertions and assumptions have been repeated so many times that, no doubt, in some cases, they have been accepted as true, but no proof has been presented and there is no proof. On the contrary, those who know weights and measures, who know the gigantic character of the task which confronts any nation which sets out to change them, know that the inherent probabilities are all in favor of the condition set forth.

APPENDIX

ARGENTINA

(Summary of eleven returned questionnaires)

Groceries: Kilogram, liter, pound. *Fruits:* Kilogram. *Milk:* Liter. *Butter and Cheese:* Kilogram. *Other Farm Products:* Kilogram, liter. *Hardware:* Kilogram, centimeter, inch, meter, yard. *Fish:* Kilogram. *Meat:* Kilogram. *Flour:* Kilogram. *Tea and Coffee:* Kilogram.

Dry Goods: Meter, yard. *Fuel:* Kilogram. *Tobacco:* Kilogram.

Ready-Made Clothing: Centimeter, inch, local numbers. "The measurements of these articles are expressed in the trade in English or metric units according to their source. Clothing, collars, hats, etc., imported from England are measured in inches and those from France in metric units." *Hats:* Centimeter, local numbers, inch. (See clothing above.) *Collars:* Centimeter, inch. "Best stores have conversion tables to inches." (See clothing above.) *Underwear and Hosiery:* Inch, centimeter. *Shoes:* Centimeter. "Imported shoes in English sizes. Local manufactures to special Argentine numbers." "The point corresponding to one-quarter of the old French inch." *Gloves:* Centimeter. *Corsets:* Centimeter.

For the Measurement of Land: Hectare, square meter, cuadra, league, vara. "Lots of land are sold in most cases by the square vara." "In many places the vara is used, also the cuadra, but these measures are not legal." "In Buenos Aires the old vara is still quite frequent." "The real estate dealers are accustomed to sell city lots by the square vara, although according to law they are liable to a severe penalty."

Lumber and Timber: Inch, foot, meter. "English measurements, though some sales are based on length in meters." "Length always in meters, breadth and thickness more often in inches." "Chiefly English measures." "By the cubic meter and square meter for 1 inch in thickness."

By Carpenters and Other Woodworkers: Metric, English. *By Stone and Brick Masons:* Metric. *By Tailors and Seamstresses:* Meter, centimeter.

In Machine Shops: Meter, inch, millimeter, centimeter, gram, kilogram. "Sizes in English measures." "Iron measurements in inches, otherwise kilo and centimeter."

In Contracts for Excavation of Ground: Cubic meter, square meter, kilogram. *In Mines and for Mining Products:* Metric ton, kilogram, meter. *In Smelting and for Smelter Products:* Meter, pulgada, kilogram, metric ton. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Length, meter; diameter, meter, foot, inch; weight, kilogram. "Meter for large sewer pipes; soil pipes, English and metric; gas and water pipes, inch."

In Ship and Boat Building: Meter, foot, inch, kilogram. *Marine Measurements:* Kilometer, meter, pie, ton, mile, knot, cubic foot. "Distances, maritime miles; charts, feet; tonnage and displacement, same as England and United States." "English measures." "As regards marine measurements, although contrary to legal provisions, people use for distance the marine mile. Charts of bays: Depths are expressed in English feet or in fathoms of 6 ft. Tonnage is expressed in Moorson tons. Displacement is expressed in English tons. Freight, English ton, metric ton."

Hay at Wholesale: Kilogram, metric ton. *Grain at Wholesale:* quintal, hectoliter, kilogram. *Meat at Wholesale:* Kilogram. *Root Crops at Wholesale:* Kilogram. *Coffee at Wholesale:* Kilogram. *Milk at Wholesale:* Liter. *Butter and Cheese at Wholesale:* Kilogram. *Garden Products at Wholesale:* Kilogram. *Rubber at Wholesale:* Kilogram.

Railway Tariff for Passengers and Freight (Load and Distance): Kilogram, metric ton, kilometer. *Loads and Rates for City Transportation:* Kilogram, metric ton. *Loads and Rates for Transportation by Muleback Across the Mountains:* Kilogram. *Railway Track Gages and Length of Lines:* Distances, kilometer; gage, English, metric. *Railway Equipment* (*units used in the construction and repairing of locomotives, cars, etc.*): English, metric.

"The only legal units for any business transaction are the metric system, but through a bad habit there has been introduced in common language the indiscriminate use of the American and Canadian legal measurements."

Mr. E. F. Du Brul writes from Buenos Aires: "Many quotations on the market are made in tons, pounds, etc. City land is sold by the square vara. Wine, etc., is sold by the pipe and barrel. I notice advertisements in the street cars of wine sold by the frasco. As large estancias change hands they are sold by the square legua. I notice that there is one ton of 918.8 kilos. I have run into a few others; for example, a metric ton of 1000 kilos; another of 1004 kilos; another of 1016 kilos, and another of 1018 kilos. Many building operations are conducted on the old Spanish measurements. Machinists and others are extremely familiar with English measurements as well as Spanish and metric because they have to use all three of them." Mr. Du Brul encloses a price list of files made in Germany and sold in Buenos Aires, and the lengths are given in all cases in pulgadas.

According to a standing announcement in THE JOURNAL of The American Society of Mechanical Engineers, the Republic of Argentina specifies that all steam boilers for government use are to be made to the Society's code. This code is the most elaborate piece of standardization ever undertaken. It includes a profusion of formulæ and specifications of the properties of materials and the strength of all parts *in English units exclusively*.

The Boston Pressed Metal Company write: "Shipments to Argentine are handled by our agent at Buenos Aires and standard English sizes are accepted and used without question. In fact, there has never been any suggestion that metric sizes were required or preferred."

The foregoing clearly shows the erroneous character of the report of the International High Commission on the Metric System in Export Trade prepared by the Bureau of Standards, to the effect that the Metric System is "obligatory" in Argentina. The same holds true, also, in respect to conditions in Brazil, Chile, Colombia, Costa Rica, Cuba, Guatemala, Mexico, Nicaragua, Peru, Spanish Honduras, and Uruguay, as shown by the summaries of the questionnaires returned from these countries, given below.

Argentina "adopted" the metric system in 1863.

BOLIVIA

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part IV, published by the Department in 1911, contains the following: "Bolivia has officially adopted the metric system, but the old Spanish weights and measures are those commonly used. All cloth is retailed by the vara."

BRAZIL

(Summary of thirty-seven returned questionnaires)

Groceries: Liter, kilogram, gallao, arroba, gram. *Fruits:* Kilogram, arroba, alqueire; conserves in ½-kilo cans. *Milk:* Liter, garrafa of ⅔ liter. *Butter and Cheese:* Kilogram, libra; butter in packages of ½, 1 and 7 pounds and ¼, ½, 1, and 3 kilograms. *Other Farm Products:* Cargueire quarta, kilogram, metric pound, liter, arroba. *Hardware:* Inch, kilogram, meter, centimeter, millimeter, metric ton, liter (*sic*). "Use all measures." *Fish:* Kilogram. *Meat:* Kilogram, liter (*sic*), arroba. *Flour:* Liter, kilogram, alqueire. *Tea and Coffee:* Tea in cans of ¼, ½, 1 and 5 English pounds and by kilogram; coffee, kilogram.

Dry Goods: Meter, jarda, covado.

Fuel: Wood, cubic meter, carroca, cargueire; coal, metric ton, kilogram; oil, kilogram and liter.

Tobacco: Kilogram, meter, arroba; fine tobacco, onca.

Ready-Made Clothing: Centimeter, meter. *Hats:* Brazilian, English, Italian and Portuguese numbers, centimeter, inch, meter (*sic*). *Collars:* Centimeter, meter (*sic*). *Underwear and hosiery:* Underwear, centimeter; hosiery, inch, centimeter, meter. *Shoes:* Centimeter, numbered sizes by no apparent system, English, Portuguese, meter (sic). *Gloves:* Letter sizes, numbered sizes by no apparent system, centimeter, inch. *Corsets:* Centimeter, meter (*sic*).

For the Measurement of Land: In the farming districts: Meter, square meter, alqueire, hectare, legua, braca, are, palmo, pollegada (*sic*), paulista, front foot, tarefa. "For agricultural lands or open lands in general the division is almost universally into alqueires." "The old Brazilian legua is generally used. "The standard throughout the State is the alqueire." In the smaller towns: Braca, alqueire, square meter, tarefa, vara, hectare, palmo, front meter, are, pollegada (*sic*). In cities: Meter, square meter, braca, are, palmo, pollegada (*sic*), hectare.

Lumber and Timber: Palmo, foot, inch, pie, pollegada, meter and palmo for length, square foot, cubic meter, centimeter. "Thickness of lumber always in English inches. Width in Eng-

lish inch by the lumber company, and Portuguese inch by others. The lengths in feet by the lumber company and Portuguese inches by others."

By Carpenters and Other Woodworkers: Meter, inch, foot, palmo, pollegada, centimeter. *By Stone and Brick Masons:* Meter, cubic meter, square meter, pollegada, centimeter, palmo. *By Tailors and Seamstresses:* Meter, centimeter.

In Machine Shops: Meter, foot, inch, palmo, kilogram, metric ton, gram, liter (*sic*). "The metric system was established by law under the Empire as the only official system. The English system, especially for metal work, is very popular."

In Contracts for Excavation of Ground: Cubic meter, palmo, braca. *In Mines and for Mining Products:* Meter, cubic meter, metric ton, kilogram, gram, oitavo, carat. *In Smelting and for Smelter Products:* Cubic meter, metric ton, inch, (*sic*) centimeter, (*sic*) kilogram, gram. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch, centimeter, meter for length. "English system chiefly; metric system infrequently." "For the measurement of earthen pipes, the internal diameter is usually given in inches. Metal tubing for gas and water is measured by weight, per kilogram. Diameters are usually measured in inches and lengths in meters." "The English measures prevail."

In Ship and Boat Building: Meter, yard, foot, inch. "Generally the English foot; exceptionally the meter." *Marine measurements:* Marine mile, foot for harbor charts, meter; freight by metric ton, cubic meter, kilogram; depths in meters or feet; knot, league. "English mile for distance; English foot for drafts." "English system." "The nautical mile is most commonly employed; Lloyds' registry is used in calculating tonnage." "Distances, English mile; tonnage, English ton; draft, English foot."

Hay at Wholesale: Arroba, kilogram. *Grain at Wholesale:* Liter, kilogram, prato, cargueiro quarta, alqueire, arroba. *Meat at Wholesale:* Kilogram, arroba. *Root Crops at Wholesale:* Kilogram, arroba, amarrado, metric ton. *Coffee at Wholesale:* Kilogram, arroba. *Milk at Wholesale:* Liter. *Butter and Cheese at Wholesale:* Kilogram, libra, jaca, arroba. *Garden Products at Wholesale:* Liter, kilogram. *Rubber at Wholesale:* Kilogram, arroba.

Railway Tariff for Passengers and Freight (Load and Distance): Kilometer, metric ton, cubic meter. *Loads and Rates for City Transportation:* Kilometer, tonelada, cubic meter, arroba, metric ton, kilogram. *Loads and Rates for Transportation by Muleback Across the Mountains:* Arroba, kilogram. *Railway Track Gages and Length of Lines:* Meter, kilometer, centimeter. *Railway Equipment (units used in the construction and repairing of locomotives, coaches, etc.):* Inch, foot, kilogram, meter. "Weight, kilo; measure, English inch."

"The official system of weights and measures, etc., is the metric system. However, the ol Brasilian system is still commonly used."

Brasil "adopted" the metric system in 1862.

CHILE

(Summary of ten returned questionnaires)

Groceries: Libra, kilogram. "Generally the libra." *Fruits:* Libra, kilogram. *Milk:* Liter, hectoliter, botella = 2/3 liter. *Butter and Cheese:* Libra, kilogram. *Other Farm Products:* Libra, kilogram, quintal, fanega. *Hardware:* Libra, kilogram. *Fish:* Libra, kilogram. *Meat:* Kilogram, libra. "Live cattle, kilo; meat, libra." *Flour:* Libra, kilogram, arroba, quintal. *Tea and Coffee:* Libra, fanega, quintal, kilogram.

Dry Goods: Vara, yard, meter. "Wholesale, yard; retail, vara."

Fuel: Kilogram, raja, cubic meter, decaliter (*sic*), almud, fanega, tonelada, metric ton, cordada.

Tobacco: Libra, quintal, kilogram, gram.

Ready-Made Clothing: Centimeter, inch. "As in United States and England." *Hats:* Local numbers, inch, centimeter. *Collars:* Centimeter. *Underwear and Hosiery:* Centimeter, inch. "As in the United States." *Shoes:* Centimeter. *Gloves:* "English sizes," local numbers, centimeter. *Corsets:* Centimeter, inch. "French and English," "English sizes."

For the Measurement of Land: In the farming districts: Hectare, cuadra, caballeria, league. In the smaller towns: Hectare, meter, cuadra, square meter, caballeria, potrero. In cities: Square meter, square vara.

Lumber and Timber: Inch, square foot, foot, board foot, cubic yard. "Sizes as in United States." "Length of native wood in Spanish varas."

By Carpenters and Other Woodworkers: Inch, foot, square foot. "The measures generally used are the foot and inch, rarely the meter." "The meter is sometimes used for the sizes of

beams." *By Stone and Brick Masons:* Square meter, cubic meter, inch, centimeter. *By Tailors and Seamstresses:* Centimeter, meter, vara.

In Machine Shops: Inch, foot. "In repair work on English and American machinery, feet and inches; on German, French and Italian, metric."

In Contracts for Excavation of Grounds: Cubic meter, vara, pie. *In Mines and for Mining Products:* Quintal, cubic meter, kilogram, tonelada, metric ton. "Long tons for ores for England; short tons for American purchase; metric for local smelters; Troy and metric for assays." *In Smelting and for Smelter Products:* Tonelada, kilogram, cubic meter, quintal. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch, foot, centimeter for sewer pipe.

In Ship and Boat Building: Tonelada, pie, pulgada, foot, inch, meter, centimeter. *Marine Measurements:* Mile, knot, kilometer, braza (fathom), ton. "For distances, the English mile; for charts of bays, the meter; for tonnage, the metric ton; for displacement, the metric ton; for freight and bulk, meter and metric weight." "English maritime mile."

Hay at Wholesale: Fanega, metric ton, kilogram, quintal, metric quintal, arroba. *Grain at Wholesale:* Fanega, arroba, quintal, metric quintal, kilogram, hectogram. *Meat at Wholesale:* Kilogram. "Wholesale, per kilo; retail, per libra." *Root Crops at Wholesale:* Quintal, libra, kilogram, arroba. *Coffee at Wholesale:* Quintal, fanega, kilogram, metric quintal. *Milk at Wholesale:* Hectoliter, liter, botella (2/3 liter). *Butter and Cheese at Wholesale:* Libra, quintal, kilogram, arroba. *Garden Products at Wholesale:* Quintal, kilogram, arroba. *Rubber at Wholesale:* Quintal.

Railway Tariff for Passengers and Freight (Load and Distance): Metric quintal, tonelada, kilogram. *Loads and Rates for City Transportation:* Quintal, tonelada, cubic meter. *Railway Track Gages and Length of Lines:* Meter, kilometer. *Railway Equipment (units used in the construction and repairing of locomotives, cars, etc.):* Kilogram, inch, foot, quintal.

"The addition of the metric system has merely added an additional system without any visible advantage. So long as the Anglo-Saxon dominates in the manufacturing world, feet, inches and pounds will be used here." "All measures are mixed. Besides metric, avoirdupois weight and feet there are many Spanish and local measures like the cajon, marco, fanega, Spanish quintal, etc." "The libra is most frequently used in the purchase and sale of goods for daily consumption." "In machine shops it may be said that up to the present the foot and inch have predominated." "The sales of the leading product of this section, nitrate of soda, are made commercially in Spanish quintals." "The Chilian hydrographic charts have scales in several units, — cables, meters and geographic miles."

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part IV, published by the Department in 1911, contains the following: "Chile has officially adopted the metric system, but in the shops throughout the country the vara is still the recognized length for retail selling."

Chile "adopted" the metric system in 1858.

COLOMBIA

(Summary of five returned questionnaires)

Groceries: "Pound and arroba of 25 English pounds," kilogram, quintal. *Fruits:* Pound, ogram, quintal, arroba. *Milk:* Botella of 360 and 750 grams. *Butter and Cheese:* Pound, ra, arroba, metric pound. *Other Farm Products:* Pound, arroba, kilogram, quintal. *Hardware* merican and English measurements generally." "English pound or arroba of 25 English inds." *Fish:* Pound, "arroba of 25 English pounds." *Meat:* Pound, libra, arroba. *Flour:* ra, pound. *Tea and Coffee:* Libra, pound, ounce, kilogram.

Dry Goods: Yard, vara, meter. "Cloths are sold indiscriminately by meters, varas, or yards ording to the origin of the goods or the whim of the buyer."

Fuel: Kilogram, burro, arroba, metric ton, English ton and pound.

Tobacco: Libra, arroba, pound.

Ready-Made Clothing: "American and French measurements." *Hats:* "American and ich measurements." "Spanish sizes." Collars: "American and French measurements." *erwear and Hosiery:* "American and French measurements." "Spanish sizes." *Shoes:* "Ameri- and French measurements." "Spanish sizes." *Gloves:* "American and French measure- ts." *Corsets:* "American and French measurements."

For the Measurement of Land: In the farming districts: Hectare, fanegada, cabuya. In maller towns: Cabuya (50 brazas), square vara. In cities: Square vara, square meter, square . "The real-estate documents always give the measure that is used indiscriminately."

Lumber and Timber: Square foot, metric, "Standard board sizes in inches."

By Carpenters and Other Woodworkers: Square foot, "Feet and inches and metric system about equally." *By Tailors and Seamstresses:* Metric, inch. *By Stone and Brick Masons:* Square foot.

In Machine Shops: Meter, foot, "English system."

In Contracts for Excavation of Ground: Cubic meter. *In Mines and for Mining Products:* "English." *In Smelting and for Smelter Products:* "English." *Sizes of Pipe for Gas, Water, Sewers, Etc.:* "English measures."

In Ship and Boat Building: Cubic ton, "English measures." *Marine Measurements:* Mile, "Metric measurements and weights." "The brasa, which corresponds to the English fathom. The English nautical league and mile, English ton and short ton; occasionally the metric ton. Displacement ton as above (English). Freight per metric ton."

Grain at Wholesale: Hectare (*sic*), pound, arroba, quintal. *Meat at Wholesale:* Pound, arroba. *Root Crops at Wholesale:* Pound, kilogram, arroba, manojo, ton. *Coffee at Wholesale:* Kilogram, arroba, quintal. *Milk at Wholesale:* Contara, botella. *Butter and Cheese at Wholesale:* Pound, arroba, metric pound. *Garden Products at Wholesale:* Pound, kilogram, arroba, quintal. *Rubber at Wholesale:* Pound, arroba, quintal, metric ton.

Railway Tariff for Passengers and Freight (Load and Distance): Kilometer. *Loads and Rates for City Transportation:* Arroba, mile, pound. *Loads and Rates for Transportation by Muleback Across the Mountains:* Arroba, mile.

Railway Track Gages and Length of Lines: Inch, foot, meter, kilometer.

"The pound in this region is the English because all the machines, platform scales and weighing instruments come from England and the United States." "As you can see, we have no uniformity of weights and measures in this country." The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part II, published by the Department in 1910, contains the following: "An instance of the conservatism of the retail merchants in this respect was strikingly shown during the recent civil war, when the Bogota importers found it necessary to get some white goods from the Barranquilla importers. On arrival the importers found them almost unsalable because they were in the coast lengths of 20 yards instead of the customary Bogota lengths of 24 yards. It would seem that, as the goods are finally retailed by the vara, the length of cuts would be immaterial, but according to the importers it has a strong effect on the salability of the cloth, and this peculiarity must be catered to in order to obtain the business."

Colombia "adopted" the metric system in 1853.

COSTA RICA

(Summary of three returned questionnaires)

Groceries: Libra, cajuela, fanega, quintal. *Fruit:* Domestic, no standard; imported, libra. *Milk:* Liter, botella (¾ gallon). *Butter and Cheese:* Libra, arroba. *Other Farm and Garden Products:* Libra, cuarillo, fanega, cajuela, quintal. *Hardware:* Pie, vara, libra, pound. *Fish:* Libra quintal. *Meat:* Kilogram, libra. *Flour:* Quintal, half quintal, libra. *Tea and Coffee:* Quintal, libra.

Dry Goods: Vara, yard.

Fuel: Coal, libra; charcoal, cuartillo; wood, no defined unit.

Ready-Made Clothing: Inch, centimeter. *Hats:* Inch. *Collars:* Inch, centimeter. *Underwear and Hosiery:* Inch, centimeter. *Shoes:* English numbers, French numbers. *Gloves:* Inch. *Corsets:* Inch.

Measurement of Land: In agricultural districts: Hectare, square vara, manzana, are. In the smaller towns: Hectare, square pie, square vara, square meter. In cities: Hectare, square pie, square vara, manzana, square meter. "The people in their transactions generally use the manzana and square vara, but the registry of documents in the government office is based entirely on the meter and the hectare."

Lumber and Timber: Lineal and cubic pie, tonelada of 27 cubic pies, ton of 1000 kilos, foot and vara for length, inch for thickness.

By Carpenters and Other Woodworkers: Superficial and cubic pie, meter, foot, vara, yard. "Indiscriminately the English foot, the Spanish vara, yard and meter." *By Tailors and Dressmakers:* Yard, vara, meter.

In Machine Shops: Quintal, libra, meter, vara, foot, yard, pound.

In Contracts for the Excavation of Ground: Tonelada, cubic meter, cubic vara, cubic foot, ıbic yard, cubic meter. *In Mines and Mineral Products:* Metric ton, tonelada, ounce. *Smelting ıd Smelter Products:* Foot, vara, yard, meter, libra, kilogram. *Pipe Sizes:* Inch, foot.

Ship and Boat Building: Cubic ton. *Marine Measurements:* Mile, league. *Hay at Whole-le:* Bale of 30 to 50 libras. *Grain at Wholesale:* Quintal, fanega, cajeula, cuartillo. *Meat at 'holesale:* Kilogram, quintal. *Root Crops at Wholesale:* Quintal, bag of 160 liters. *Coffee at 'holesale:* Quintal, tonelada. *Milk at Wholesale:* Botella. *Butter and Cheese at Wholesale:* uintal, arroba. *Garden Products at Wholesale:* Quintal, bag of 160 liters. *Rubber at Wholesale:* uintal.

Railway Tariff: Passengers per mile; freight per quintal, kilo, metric ton, cubic pie, cubic ın, cubic meter per kilometer. *Urban Transportation:* Quintal. *Muleback Transportation Across 'ountains:* Arroba. *Railway Gage:* Feet and inches.

"Although the law No. 35 of July 17, 1884, established the metric system as obligatory, the ›ople and the merchants do not use it ordinarily in their transactions."

Costa Rica "adopted" the metric system in 1858.

CUBA

(Summary of three returned questionnaires)

Groceries: Libra, quintal. *Fruits:* Libra. *Milk:* Botella. *Butter and Cheese:* Libra. *her Farm Products:* Libra. *Hardware:* "English measures." *Fish:* Libra. *Meat:* Libra. *our:* Libra. *Tea and Coffee:* Libra. *Dry Goods:* Vara, yard.

Fuel: Libra, cuerda.

Tobacco: Libra, quintal.

Ready-Made Clothing: Inch, "American measures." *Hats:* Centimeter, "American meas-es." *Collars:* Inch, centimeter. *Underwear and Hosiery:* Inch, centimeter, "American meas-es." *Shoes:* Centimeter, "American measures." *Gloves:* Centimeter, inch, "American meas-es." *Corsets:* Inch, centimeter, "American measures."

For the Measurement of Land: In the farming districts: Caballeria, leagua, carreaux, "the uivalents being inserted in all public documents according to law." In the smaller towns: Ca-lleria, vara, meter, cubana. In cities: "Parcels of 1000 square varas."

Lumber and Timber: Foot, inch, kilogram (*sic*).

By Carpenters and Other Woodworkers: Foot, inch, kilogram (*sic*). *By Tailors and Seam-esses:* Meter, centimeter. *By Stone and Brick Masons:* Meter, foot, inch, kilogram (*sic*).

In Machine Shops: Inch, centimeter, pound.

In Contracts for Excavation of Ground: Cubic meter. *In Mines and for Mining Products:* ›n, metric. "Transactions with the United States in feet, inches and pounds." *In Smelting d for Smelter Products:* Centimeter, inch. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch.

In Ship and Boat Building: Foot, inch, meter, ton. *Marine Measurements:* League, ton le, "foot for depth."

Hay at Wholesale: Pound, English quintal. *Grain at Wholesale:* Pound, English quintal. *eat at Wholesale:* Pound, Spanish and English quintal. *Root Crops at Wholesale:* Pound, English intal. *Coffee at Wholesale:* Pound, English and Spanish quintal. *Milk at Wholesale:* Botella. *tter and Cheese at Wholesale:* Pound, English quintal. *Garden Products at Wholesale:* Pound.

Railway Tariff for Passengers and Freight (Load and Distance): Meter, kilogram, kilometer. *ads and Rates for City Transportation:* Meter, kilogram. *Railway Track Gages and Length of ıes:* Foot, inch, kilometer. *Railway Equipment (units used in the construction and repairing of omotives, cars, etc.):* "American and English equipment."

"American measures generally used and in each industry the name is used that corresponds th the English meaning."

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce d Labor, Part I, published by the Department in 1909, contains the following: "Though the etric system of weights and measures is the official and legal system in Cuba, some of the Spanish ights and measures are still largely used, among them being the arroba and the vara. Cloth is ught by the importer by the meter or yard, and is retailed in the shops by the yard or the vara, e vara being more commonly used."

Cuba is one of the thirty-four countries which, according to the American Metric Association, ıve "adopted" the metric system.

DOMINICAN REPUBLIC

Commerce Reports, published by the Department of Commerce, prints the following communication, dated February 20, 1918, from Consul Arthur McLean of Puerto Plata: "The metric system of weights and measures has been legally adopted by the Dominican Republic. The only place, however, where the metric system is applied to trade here is in the municipal markets; avoirdupois weights are used in all other mercantile transactions, although the metric system is in force in the customs and other Government institutions. The kilometer and the league are the two units most generally used in computing distances. Jobbers use the English yard in selling cotton goods to the retailers, while the latter in turn sell to their customers by the vara or Spanish yard, measuring 33 inches. While quotations may be made by American houses to their clients in the Dominican Republic in either metric or English units, the latter are equally acceptable, if not preferred."

ECUADOR

(Summary of five returned questionnaires. One of the questionnaires, in English, reports pounds where, in view of the others, libras are probably meant and are so here reported.)

Groceries: Libra, quintal. *Milk:* Liter, gallon. *Butter and Cheese:* Libra, arroba, quintal. *Other Farm Products:* Arroba, quintal. *Hardware:* Libra, arroba, quintal; pipe by the foot, sheet iron and zinc by the pound, nails and tacks by the pound and ounce. *Fish:* Arroba, quintal. *Meat:* Libra, kilogram. *Flour:* Libra, kilogram, quintal. *Tea and Coffee:* Libra. *Dry Goods:* At retail, vara; at wholesale, yard, meter.

Tobacco: Libra, quintal.

Ready-Made Clothing: Inch. *Hats:* Centimeter. *Collars:* Centimeter. *Underwear and Hosiery:* Inch, centimeter. *Shoes:* Centimeter, English sizes. *Gloves:* Centimeter, inch. *Corsets:* Centimeter, inch.

For the Measurement of Land: In the farming districts: Hectare, cuadra, square meter. In the smaller towns: Square meter, cuadra. In cities: Square meter, vara. "In the cities the buildings are measured by the meter, the lots by the vara."

Lumber and Timber: Square foot, pie, foot, pulgada, inch, centimeter; length in varas, circumference in palmas.

By Carpenters and Other Woodworkers: Square foot, pie, pulgada, vara. *By Tailors and Seamstresses:* Centimeter.

In Machine Shops: Centimeter, millimeter, pulgada, inch, meter. "The common standard is the English inch."

In Contracts for Excavation of Ground: Square meter, cubic meter, vara. *In Mines and for Mining Products:* Kilogram, ton, tonelada, quintal. *In Smelting and for Smelter Products:* Quintal, pound, kilogram. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch, centimeter, meter for length.

In Ship and Boat Building: Ton, meter, vara. *Marine Measurements:* Kilometer, meter, vara, league, metric ton, English ton, tonelada, mile, knot, brasa, paja, malina, buey.

Hay at Wholesale: Quintal. *Grain at Wholesale:* Fanega, quintal. *Meat at Wholesale:* Kilogram. *Root Crops at Wholesale:* Kilogram, quintal. *Coffee at Wholesale:* Quintal. *Milk at Wholesale:* Gallon "of 4 liters," liter. *Butter and Cheese at Wholesale:* Libra. *Rubber at Wholesale:* Quintal, kilogram.

Railway Tariff for Passengers and Freight (Load and Distance): Kilometer. *Loads and Rates for City Transportation:* Weight, cubic pie. *Railway Track Gages and Length of Lines:* Meter, kilometer, inch. *Railway Equipment (units used in the construction and repairing of locomotives, coaches, etc.):* American.

"The Spanish inch, foot and ton are used as are other measures, although the metric measurements are sometimes used." "The Spanish pound is used in weighing everything." "While the metric system is legal, it is not enforced."

(Reply to a questionnaire sent out by Mr. Henry R. Towne)

Legal Standards: Metric system used by the Government.

Common Standards: The public uses generally the old Spanish (Castilian) measures, the vara, the libra, and the gallon.

Commercial Use: Metric system used in business with foreign countries except the United ates and Great Britain, in which case the British system is used. In domestic business only the anish system is used.

Domestic Use: Only the Spanish system in domestic use.

Measuring Implements: Spanish measures chiefly.

Dual Standards: The old Spanish (Castilian) is preferred simply as a matter of habit "handed wn by the Conquistadors."

Adoption of Metric System: Metric system adopted about 30 years ago.

Bookkeeping, Invoicing, Etc.: Bookkeeping about half in metric and half in old Spanish its, but only the latter used in making out domestic invoices. Foreign invoices about 90 per nt metric and 10 per cent old Spanish. Business records about half and half.

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce d Labor, Part IV, published by the Department in 1911, contains the following: "Cloth is bought d sold by the importer by the yard, meter or vara, but is always retailed by the vara."

Ecuador "adopted" the metric system in 1856.

GUATEMALA

(Summary of four returned questionnaires)

Groceries: Libra, quintal. *Milk:* Liter. *Butter and Cheese:* Libra. *Fish:* Libra. *Meat:* bra. *Flour:* Libra, quintal. *Tea and Coffee:* Libra.

Dry Goods: Vara.

Fuel: Carga, red.

Tobacco: Libra.

Ready-Made Clothing: Inch. *Hats:* Inch, centimeter. "The two standards are used ifferently." *Collars:* Inch, centimeter. "The two standards are used indifferently." *Underear and Hosiery:* Inch. *Shoes:* English sizes, French sizes.

Gloves: Inch. *Corsets:* Inch. "The importers usually sell all cloths, that is to say, men's oths, by the yard. The retailers often and almost solely use the vara. The meter is used very tle and for the most part only between importers and buyers at wholesale."

Measurement of Land: In agricultural districts: Caballeria, manzana, cuerda, fanega, almud. smaller towns: Cuerda. In cities: Square vara.

Lumber and Timber: Foot and inch.

By Carpenters and Other Woodworkers: Foot and inch. *By Stone and Brick Masons:* Cubic rd, square vara, cuadrada. *By Tailors and Seamstresses:* Yard, vara.

In Blacksmith Shops: Libra, vara, meter. *In Machine Shops:* Foot and inch.

In Contracts for the Excavation of Ground: Cubic pie, cubic yard. *Mining and Mine Products:* glish ton of 2000 lb. *Sizes of Pipe:* Inch.

Grain at Wholesale: Libra, quintal, fanega. *Meat at Wholesale:* Libra, arroba. *Root Crops Wholesale:* Libra, quintal. *Coffee at Wholesale:* Libra, quintal. *Milk at Wholesale:* Liter, tella. *Butter and Cheese at Wholesale:* Libra. *Rubber at Wholesale:* Libra, quintal.

Railway Tariff: Passengers per mile, freight per pound per mile. *Urban Trucking:* Mile. *alway Track Gage:* 3 ft.

"The artisans of the country use in their calculations the Spanish vara as the standard. reigners use the yard or the meter indifferently, but the lumber dealer and the dealer in logs sell thousands of square feet (English)."

(Reply to a Questionnaire sent out by Mr. Henry R. Towne)

Legal Standards: Metric.

Common Standards: Chiefly the old units. The people generally use the Spanish vara, the arta, and the libra.

Commercial Use: Metric system generally used in business.

Domestic Use: In domestic life the old Spanish measures are generally used.

Measuring Implements: Weighing scales are sold marked on one side in libras and on the other e in kilograms. Measures of length are marked on one side with the cuarta and on the other with e meter. Measures of volume comprise only the liter and the vara or cubic meter.

Dual Standards: The people continue to use the old Spanish measures from habit and because ey know them better than the others.

Adoption of Metric System: The metric system was adopted here more than twenty years o, when the Republic was established.

Bookkeeping, Invoicing, Etc.: The vara and the meter or yard are used indifferently.

"Our standard of weight is the quintal of 100 Spanish pounds. Our standard of measure is the botella."

According to the Report to the International High Commission on the Metric System in Export Trade prepared by the Director of the Bureau of Standards, the metric system is "obligatory" in Guatemala.

Guatemala "adopted" the metric system in 1894.

HAITI

Factors in Foreign Trade, published by the Department of Commerce and Labor, 1912, gives the following information:

"*Weights and Measures:* Metric system, but pounds, tons and gallons are generally used in commerce and statistics. The pound of 500 grams (1.1023 pounds avoirdupois) is adopted in the customs; the ton is 2000 pounds; gallon is equivalent to United States gallon."

MEXICO

(Summary of ten returned questionnaires)

Groceries: Kilogram. *Fruits:* Kilogram. *Milk:* Liter, cuartillo. *Butter and Cheese:* Kilogram, pound. *Other Farm Products:* Kilogram, metric ton, arroba, carga, cuartillo. *Hardware:* Kilogram, meter, "as in U. S." *Fish:* Kilogram. *Meat:* Kilogram. *Flour:* Kilogram, arroba, carga. *Tea and Coffee:* Kilogram, libra, pound.

Dry Goods: Kilogram (*sic*), meter, centimeter, vara, yard.

Fuel: Kilogram, cord, quintal, metric ton, troje, sontla.

Tobacco: Kilogram.

Ready-Made Clothing: Meter, yard, inch, centimeter, kilo (*sic*). "French and American indiscriminately." "As in U. S." *Hats:* Meter (*sic*), yard (*sic*), inch, centimeter. "French or American indiscriminately." "As in U. S." *Underwear and Hosiery:* Meter (*sic*), yard (*sic*), inch, centimeter. "French or American indiscriminately." "As in U. S."

Shoes: Meter (*sic*), yard (*sic*), centimeter, English sizes. "French or American indiscriminately." "As in U. S." *Corsets:* Meter (*sic*), yard (*sic*), centimeter, inch. "French or American indiscriminately." "As in U. S." *Gloves:* Meter (*sic*), yard (*sic*), inch, centimeter. "French or American indiscriminately." "As in U. S." "If material is from France, the meter; if from the United States, the yard."

For the Measurement of Land: In the farming districts: Hectoliter (*sic*), liter (*sic*), hectare, sitio, caballeria, acre, kilometer. In the smaller towns: Hectoliter (*sic*), liter (*sic*), hectare, square meter, acre, kilometer. In cities: Hectoliter (*sic*), liter (*sic*), hectare, meter, square meter, acre, kilometer.

Lumber and Timber: Foot, inch, cubic foot, meter, centimeter, pulgada, pie, kilogram (*sic*).

By Carpenters and Other Woodworkers: Foot, inch, meter, centimeter, pulgada, pie. *By Tailors and Seamstresses:* Meter, centimeter, vara. *By Blacksmiths:* Metric. *By Stone and Brick Masons:* Foot, inch, meter, square meter, kilogram, centimeter.

In Machine Shops: Inch, kilogram, meter, centimeter.

In Contracts for Excavation of Ground: Cubic meter, square meter, meter. *In Mines and for Mining Products:* Cubic yard, metric ton, square meter, kilogram, onza, meter. *In Smelting and for Smelter Products:* Foot, meter, metric ton. *Sizes of Pipes for Gas, Water, Sewers, Etc.:* Foot, inch, meter, centimeter.

In Ship and Boat Building: Meter, foot, kilogram. *Marine Measurements:* League, nautical mile, cubic meter, metric ton.

Hay at Wholesale: Kilogram, ton, arroba, metric ton. *Grain at Wholesale:* Quintal, kilogram, hectoliter, carga, cuartillo. *Meat at Wholesale:* Kilogram. *Root Crops at Wholesale:* Kilogram, quintal. *Coffee at Wholesale:* Quintal, kilogram. *Milk at Wholesale:* Liter, cuartillo, gallon. *Butter and Cheese at Wholesale:* Kilogram, pound (probably libra). *Garden Products at Wholesale:* Kilogram, quintal. *Rubber at Wholesale:* Pound (probably libra), kilogram.

Railway Tariff for Passengers and Freight (Load and Distance): Kilogram, kilometer, metric ton, cubic meter, mile, ton. *Loads and Rates for City Transportation:* Kilogram, kilometer, carga. *Loads and Rates for Transportation by Muleback Across the Mountains:* Carga, arroba, kilogram, kilometer. "The old weight (1 carga = 300 libras) still holds its own when dealing with muleback transportation." *Railway Track Gages and Length of Lines:* Kilometer, centimeter, foot, inch. *Railway Equipment* (*units used in the construction and repairing of locomotives, coaches, etc.*): Foot, inch, metric kilogram (*sic*). "As in U. S." "All transportation here is done by boat on a long ton basis."

"In many cases the Spanish weights are used." "In many cases the libra and vara are used."

According to the Report to the International High Commission of the Metric System in xport Trade prepared by the Director of the Bureau of Standards, the metric system is "obliga- ory" in Mexico.

Mexico "adopted" the metric system in 1862.

NICARAGUA

(Summary of three returned questionnaires)

Groceries: Libra, kilogram. *Milk:* Liter, gallon, botella (1/5 gallon). *Butter and Cheese:* ibra, arroba. *Other Farm Products:* Libra, quintal, fanega. *Hardware:* Libra, kilogram. *Fish:* ibra. *Meat:* Libra. *Flour:* Libra, kilogram. *Tea and Coffee:* Libra, quintal.

Dry Goods: Vara, yard, meter.

Fuel: Libra, corcada, marco, cordal, cuartillo.

Tobacco: Libra.

Ready-Made Clothing: Inch, centimeter. *Hats:* "English and metric system." *Collars:* English and metric system." *Underwear and Hosiery:* "English and metric system." *Shoes:* entimeter. *Gloves:* "The measure of the country of origin." *Corsets:* "The measure of the untry of origin."

For the Measurement of Land: In the farming districts: Manzana, hectare, vara, meter. In e smaller towns: Manzana, hectare, vara, meter. In cities: Manzana, vara, cuadra, meter.

Lumber and Timber: Vara, pulgada.

By Carpenters and Other Woodworkers: Vara, pulgada, tonelada (*sic*). *By Stone and Brick asons:* Vara, pulgada, tonelada (*sic*). *By Tailors and Seamstresses:* Vara, centimeter, yard, eter.

In Machine Shops: Inch, centimeter, vara.

In Contracts for Excavation of Ground: Vara. *In Mines and for Mining Products:* "English stem," tonelada. *In Smelting and for Smelter Products:* "English system." *Sizes of Pipe for s, Water, Sewers, Etc.:* Inch, pulgada.

Grain at Wholesale: Libra, fanega. *Meat at Wholesale:* Arroba, libra, kilogram. *Root Crops Wholesale:* Quintal. *Coffee at Wholesale:* Libra, quintal. *Milk at Wholesale:* "Cantaro, of out 5 gallons." *Butter and Cheese at Wholesale:* Libra, kilogram. *Rubber at Wholesale:* Libra, intal.

Railway Tariff for Passengers and Freight (Load and Distance): Kilogram, kilometer. *Loads d Rates for City Transportation:* Kilogram. *Loads and Rates for Transportation by Muleback ross the Mountains:* Libra. *Railway Track Gages and Length of Lines:* Gage, foot, inch; length, ometer. *Railway Equipment* (*units used in the construction and repairing of locomotives, cars, .):* "All American."

"The metric system of weights and measures is the official and lawful system of the Republic, t owing to the preponderance of trade with the United States, the influences of the system obtain- ; there are felt in all commercial transactions." "The introduction of all imports is, however, sed on the kilo, but throughout the Republic articles are retailed by the libra. Liquids when ported are measured by the liter, yet the American gallon or quart is commonly known. Dis- ices are computed in kilometers, but the yard of 36 inches is used almost as much as the vara of inches or the meter of 39.37 inches. So it might be said that the English system is almost as nmon as the metric."

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce d Labor, Part I, published by the Department in 1909, contains the following: The 24-inch nta retails at 40 centavos a vara. The turkey-red shirting is mainly from England, retailing at centavos a vara. The usual price of a 24-inch print is 60 centavos a vara."

According to the Report to the International High Commission on the Metric System in port Trade prepared by the Director of the Bureau of Standards, the metric system is "obliga- y" in Nicaragua.

Nicaragua is one of the thirty-four countries which, according to the American Metric Associa- n, have "adopted" the metric system.

PANAMA

(Summary of five returned questionnaires. In view of the quotation below, libra has been uniformly interpreted as pound)

Groceries: Pound, ounce. *Fruits:* Pound, ounce. *Milk:* Quart, botella. *Butter and eese:* Pound, ounce. *Other Farm Products:* Pound, English quintal. *Hardware:* Pound,

English quintal. *Fish:* Pound, English quintal. *Meat:* Pound, English quintal. *Flour:* Pound, English quintal, "barrel of 196 pounds." *Tea and Coffee:* Pound, ounce, English quintal.

Dry Goods: Yard, vara. *Fuel:* Long ton, short ton, English quintal, cord.

Tobacco: Pound, ounce, English quintal.

Ready-Made Clothing: Hats: Collars: Underwear and Hosiery: Shoes: Gloves: Corsets: Inch, metric. "The articles mentioned are imported almost exclusively from the United States and the measures are the same as in that country." "A few French articles are metric sizes."

For the Measurement of Land: In the farming districts: Hectare, square meter. In the smaller towns: Hectare, square meter. In cities: Square meter.

Lumber and Timber: Inch, foot, square and cubic foot.

By Carpenters and Other Woodworkers: Inch, "some centimeters." *By Stone and Brick Masons:* Inch, centimeter, "American generally." *By Tailors and Dressmakers:* Yard, inch, centimeter, "American generally."

In Machine Shops: Inch, centimeter, pound, English quintal.

In Contracts for Excavation of Ground: Cubic meter, yard. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch.

In Ship and Boat Building: Inch, centimeter. *Marine Measurement:* Short ton, ton of 40 cu. ft., marine mile.

Hay at Wholesale: Pound. *Grain at Wholesale:* Pound, English quintal. *Meat at Wholesale:* Pound, English quintal. *Root Crops at Wholesale:* Pound. *Coffee at Wholesale:* Pound, English quintal. *Milk at Wholesale:* Quart, botella, gallon. *Butter and Cheese at Wholesale:* Pound. *Garden Products at Wholesale:* Pound, English quintal. *Rubber at Wholesale:* Pound.

Railway Tariff for Passengers and Freight (Load and Distance): Mile, pound, cubic foot. *Loads and Rates for City Transportation:* Pound. *Railway Track Gages and Length of Lines:* Inch, mile. *Railway Equipment (units used in the construction and repairing of locomotives, cars, etc.* Inch.

"The Spanish units are never used here and while the metric system is the official standard for the country, with the exception of lands, it is seldom used in Panama, American (English) standards of weight and measure being in universal use."

Panama "adopted" the metric system in 1857.

PERU

(Summary of seven returned questionnaires)

Groceries: Kilogram. *Milk:* Liter, botella of 0.75 liter. *Butter and Cheese:* Libra, kilogram. *Other Farm Products:* Libra, kilogram. *Hardware:* Libra, pie. *Fish:* Kilogram, libra. *Meat:* Kilogram, libra. *Flour:* Kilogram, libra. *Tea and Coffee:* Kilogram, libra.

Dry Goods: Meter, vara.

Fuel: Kilogram, quintal, libra.

Tobacco: Kilogram. (Government monopoly.)

Ready-Made Clothing: Centimeter. *Hats:* Centimeter, "English numbers." *Collars:* Centimeter. *Underwear and Hosiery:* Centimeter, "Special measure." *Shoes:* Centimeter, "Special measure." *Gloves:* Centimeter, "Special measure." *Corsets:* Centimeter.

For the Measurement of Land: In the farming districts: Fanegada, topo, cuadra, square vara. "Sale and registry by the fanegada." In the smaller towns: Square meter, fanegada, topo, cuadra; "Sale and registry by the fanegada." In cities: Square meter, square vara, fanegada. "Sale and registry by the fanegada."

Lumber and Timber: Foot, inch, square foot; "Spanish foot for cedar."

By Carpenters and Other Woodworkers: Foot, inch, square foot, meter, "English system." *By Stone and Brick Masons:* Meter, square meter, arroba. *By Tailors and Seamstresses:* Centimeter, meter, yard.

In Machine Shops: Meter, inch, foot, quintal. "English system chiefly. A few jobs for European-built machinery are handled on the metric system."

In Contracts for Excavation of Ground: Cubic meter. *In Mines and for Mining Products:* Tonelada, metric ton, cubic meter, gallon of 3 3/4 liters for petroleum products. "Marco, a weight per cajon of 12,000 marcos. Troy ounces per ton. Grams per metric ton." "Spanish, English and metric. *In Smelting and for Smelter Products:* Kilogram, libra, foot. "The same as mining." *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Meter, foot, inch, "Generally English feet and inches and their fractions."

In Ship and Boat Building: Meter, foot, inch, kilogram, registered ton. "Generally the English measures." *Marine Measurements:* Mile, ton, cubic meter, knot, brasa (fathom of 6 English feet), metric ton. "Generally the English measures."

Hay at Wholesale: Quintal, metric quintal. *Grain at Wholesale:* Quintal, fanega, metric quintal. *Meat at Wholesale:* Kilogram, metric quintal, libra. *Root Crops at Wholesale:* Quintal, metric quintal, libra. *Coffee at Wholesale:* Quintal, libra. *Milk at Wholesale:* Liter. *Butter and Cheese at Wholesale:* Quintal, kilogram, libra. *Garden Products at Wholesale:* Arroba. *Rubber at Wholesale:* Tonelada, kilogram, quintal.

Railway Tariff for Passengers and Freight (Load and Distance): Kilometer, quintal, metric ton, cubic meter. *Loads and Rates for City Transportation:* Metric ton, kilogram. *Loads and Rates for Transportation by Muleback Across the Mountains:* Quintal, per kilometer. *Railway Track Gages and Length of Lines:* Meter, kilometer. *Railway Equipment (units used in the construction and repairing of locomotives, cars, etc.):* Meter, foot, inch, tonelada, kilogram.

"At the present time there are many who buy and sell, using other measures which are not metric decimal." "The metric system is the legal system in Peru but the other measures named have not yet been banished."

Commerce Reports for April 29, 1918, contains a report from Commercial Attaché W. F. Montavon, of Lima, in which are given particulars of new Peruvian exports duties. The new rates provide for a duty on copper bars per *short ton*, and on sugar, cotton and wool per *Spanish quintal*. Italicized words are verbatim from the report.

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part IV, published by the Department in 1911, contains the following: "The Peruvian importers buy cotton goods by the yard, the meter, or the vara. . . . Although the country has officially adopted the metric system, cloth is always retailed by the vara."

Peru "adopted" the metric system in 1862.

PORTO RICO

In 1913, Mr. F. S. Holbrook, Associate Physicist at the Bureau of Standards, went to Porto Rico as the representative of the Bureau to coöperate with the local legislature in connection with weights and measures legislation. Mr. Holbrook's report of his investigations contains the following: "This, then, was the condition of affairs when the work was commenced: The kilogram, the United States pound and the Spanish libra or pound for weight; the liter, the quart, the cuartillo for liquid measure; the meter, the yard and the vara for length measure; the hectare, the acre and cuerda for land measure, were all in use side by side. A little over 50 per cent of the weights found in use were of the Spanish system, the remainder being about equally divided between weights of the metric system and of our customary system. Of the liquid measures tested, the very great majority were cuartillos or subdivisions thereof,"

As the outgrowth of Mr. Holbrook's visit to Porto Rico the weights and measures of the United States, with the exception of the bushel and its subdivisions, were placed "upon an equal basis" with the metric units, the result being shown in the following reply to a questionnaire sent out by Mr. Henry R. Towne.

Legal Standards: Metric, U. S., and a few Spanish.

Common Standards: Metric, U. S., and some Spanish.

Railroad Distances: Kilometers.

Weights: Generally pounds, but also kilos.

Volume: Liter, Spanish quart, but generally U. S. quart.

Land: Spanish cuerda and metric hectare, the latter in deeds.

Cubic Meter: Used in public contracts.

Commercial Use: Commercial transactions on U. S. basis; Government transactions on metric basis.

Domestic Use: U. S. standards in common use and are legal. Metric catalogs of no use.

Measuring Implements: Both U. S. and metric in common use.

Dual Standards: Old Spanish measures generally displaced by U. S. measures, except the "cuerda" for land records. Metric system also legal; chiefly used in Government transactions.

Adoption of Metric System: By Spanish Government in early 90's. By local legislature in 1898. U. S. Standards also legalized since latter date.

Bookkeeping, Invoicing, Etc.: U. S. Standards used almost exclusively.

The William J. Dines, Jr., Co. write: "I have been with engineers and workmen in all parts of the Island, and very seldom find anyone using anything but the American standard."

The report of Mr. Wm. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part IV, published by the Department in 1911, contains the following: "In

San Juan most goods are retailed by the yard as the people there demand this length, but in the remainder of the island the usual measure is the Spanish vara of 83.6 centimeters."

All of the above should be compared with the statement by Mr. Fred R. Drake as quoted in the preamble.

SAN SALVADOR

(Summary of one returned questionnaire)

Groceries: Almud. *Milk:* Liter. *Butter and Cheese:* Libra. *Other Farm Products:* Libra. *Hardware:* Pound, quintal. *Fish:* Libra. *Meat:* Libra. *Flour:* Bulto. *Tea and Coffee:* Libra.

Dry Goods: Vara.

Fuel: Carga.

Collars: English numbers.

For the Measurement of Land: In the farming districts; Manzana, caballeria. In the smaller towns: Vara, "with metric measures always used in the documents." In cities: Meter and millimeter (*sic*).

By Stone and Brick Masons: Vara, pie, pulgada. *By Tailors and Seamstresses:* Vara, meter, millimeter.

In Contracts for Excavation of Ground: Cubic meter. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch.

Grain at Wholesale: Fanega, arroba. *Meat at Wholesale:* Libra. *Coffee at Wholesale:* Quintal. *Milk at Wholesale:* Botella. *Butter and Cheese at Wholesale:* Libra.

Railway Tariff for Passengers and Freight (Load and Distance): Cubic foot, quintal, kilometer. *Loads and Rates for City Transportation:* Quintal. *Loads and Rates for Transportation by Muleback Across the Mountains:* Arroba.

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part I, published by the Department in 1909, contains the following: "Practically all exported yarn is put up in either five- or ten-pound paper-covered packets and either eighty or forty of these packed to the bale. Yarn is retailed here in ten-pound lots, but two five-pound packets are preferred to one ten-pound. . . . These splits are 20 to 26 inches wide, and retail at a real a vara."

SPANISH HONDURAS

(Summary of three returned questionnaires)

Groceries: Pound, arroba. *Fruits:* Pound. *Milk:* Liter, bottella, pint. *Butter and Cheese:* Libra, pound. *Other Farm Products:* Pound. *Hardware:* Pound. *Fish:* Libra, pound. *Meat:* Libra, pound. *Flour:* Libra, pound. *Tea and Coffee:* Libra, pound.

Dry Goods: Vara, yard.

Fuel: Carga, pound, cuerda.

Tobacco: Libra, pound.

Ready-Made Clothing: Inch, "Same as in United States." *Hats:* "American and French sizes." *Collars:* "American and French sizes." *Underwear and Hosiery:* "American and French sizes." *Shoes:* "American and French sizes." *Gloves:* "American and French sizes." *Corsets:* "American and French sizes." "General American sizes of wearing apparel in use."

For the Measurement of Land: In the farming districts: Caballeria, manzana, hectare. In the smaller towns: Caballeria, manzana, hectare, foot. In cities: Caballeria, manzana, hectare, foot. "The official standard is the hectare. Deeds in hectares and others in manzanas according to original measure. In towns the lots are measured in English feet and are so registered. Also large parcels in the country measured in caballerias."

Lumber and Timber: Laufenberg rule, "Exactly the same as American sizes."

By Carpenters and Other Woodworkers: Foot, inch. *By Stone and Brick Masons:* Inch, "American sizes." *By Tailors and Seamstresses:* Metric, foot.

In Machine Shops: Inch, foot, pound, "American sizes."

In Contracts for Excavation of Ground: Foot, inch, "American sizes." *In Mines and for Mining Products:* Cubic foot, ton, metric ton, "American sizes." *In Smelting and for Smelter Products:* Pound, ton, "American sizes." *Sizes of Pipe for Gas, Water, Sewers, etc.:* "Generally American sizes."

In Ship and Boat Building: "Same as in United States." *Marine Measurements:* Foot, "American sizes."

Hay at Wholesale: Libra. *Grain at Wholesale:* Carga, libra, medida. *Meat at Wholesale:* Libra, pound. *Root Crops at Wholesale:* Pound. *Coffee at Wholesale:* Carga, libra. *Milk at Wholesale:* Liter. *Butter and Cheese at Wholesale:* English arroba, libriado. *Garden Products at Wholesale:* Libra, pound. *Rubber at Wholesale:* Pound, libra, quintal.

Railway Tariff for Passengers and Freight (Load and Distance): Kilogram, kilometer, mile. *Loads and Rates for Transportation by Muleback Across the Mountains:* Arroba, pound. *Railway Track Gages and Length of Lines:* Foot, inch, kilometer. *Railway Equipment (units used in the construction and repairing of locomotives, cars, etc.):* "English units used in repairs."

"The English yard is chiefly used in the larger and better stores. The vara is used frequently in smaller stores selling at retail to certain classes, but the people are accustomed to and demand the English yard." "All articles not named above are valued according to agreement per arroba or carga, always keeping the English as the standard. The arroba is 25 pounds and the carga is 8 arrobas or 200 pounds."

The report of Mr. W. A. Graham Clark, Commercial Agent of the Department of Commerce and Labor, Part I, published by the Department in 1909, contains the following: "The importers sell to the retailers by the yard and the retailers sell at practically the same price by the vara . . . This country has officially tried to adopt the metric system, but the natives cling to the vara and the arroba as their measures of length and weight."

Honduras is one of the thirty-four countries which, according to the American Metric Association, have "adopted" the metric system.

URUGUAY

(Summary of four returned questionnaires)

Groceries: Kilogram. *Milk:* Liter. *Butter and Cheese:* Kilogram. *Other Farm Products:* Kilogram. *Hardware:* Kilogram, meter. *Meat:* Kilogram. *Flour:* Kilogram. *Tea and Coffee:* Kilogram.

Dry Goods: Meter.

Fuel: Metric ton.

Tobacco: Kilogram.

Ready-Made Clothing: Centimeter. *Hats.* Centimeter, English numbers. *Collars:* Centimeter. *Underwear and Hosiery:* Meter, centimeter, inch. *Gloves:* "As in North America." "Universal numbering." *Corsets:* Centimeter.

For the Measurement of Land: In the farming districts: Hectare. "The cuadra is still commonly used but is prohibited in the documents." In the smaller towns: Hectare, square meter In cities: Hectare, square meter.

Lumber and Timber: Meter, centimeter, foot, inch. "Officially the meter, customarily per thousand feet."

By Carpenters and Other Woodworkers: Meter, centimeter, English foot, inch. "English foot and inch generally used." *By Tailors and Seamstresses:* Centimeter, kilo (*sic*), English measures. *By Stone and Brick Masons:* Kilogram, meter, metric ton.

In Machine Shops: Kilogram. "Officially the meter and sub-multiples, practically, following the custom, the English inch." "English measures generally."

In Contracts for Excavation of Ground: Cubic meter, meter. *In Mines and for Mining Products:* Kilogram, cubic meter. *In Smelting and for Smelter Products:* Kilogram, metric ton. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* "English measures, but in official and public documents these are reduced to centimeters." "Officially the meter, practically the pulgada."

In Ship and Boat Building: Metric. *Marine Measurements:* Mile, knot, foot, cable, ton, meter for sounding, brasa, "but in official and public documents only the decimal measures appear." "Officially the kilometer; to a large extent the marine mile." "In practice there is no effort to abolish completely the English measures."

Hay at Wholesale: Kilogram, metric quintal. *Grain at Wholesale:* Kilogram, metric quintal.

Meat at Wholesale: Kilogram. *Root Crops at Wholesale:* Metric quintal. *Coffee at Wholesale:* Kilogram, metric quintal. *Milk at Wholesale:* Liter, hectoliter. *Butter and Cheese at Wholesale:* Kilogram. *Rubber at Wholesale:* Kilogram.

Railway Tariff for Passengers and Freight (Load and Distance): Kilogram, kilometer. *Railway Track Gages and Length of Lines:* Metric.

"The metric system only has been used in Uruguay for at least fifty years and any one who uses any other system runs the risk of fine and imprisonment. . . . In the case of land measurement, a few old Spanish measures are authorized. This letter, according to the laws of Uruguay, must be copied in a letter-press book. Each page of the letter-press book is signed by one of the judges of the Commerce Court and may at any time be required in Court. By using in our correspondence copied in the letter-press book any terms of weights and measures not recognized by

law, we run the risk of punishment." "The introduction of the new system proved, however, a difficult and tedious process."

Uruguay "adopted" the metric system in 1862.

VENEZUELA

(Summary of five returned questionnaires)

Groceries: Libra, kilogram. *Fruits:* Kilogram, Libra. *Milk:* "Jar of 27 botellas," liter. *Butter and Cheese:* Libra, kilogram. *Other Farm Products:* Libra, metric. *Hardware:* Libra, metric. *Fish:* Libra, kilogram. *Meat:* Libra, kilogram. *Flour:* Libra, kilogram, arroba. *Tea and Coffee:* Libra, kilogram.

Dry Goods: Vara, meter, yard.

Fuel: Tonelada, metric ton.

Tobacco: Metric.

Ready-Made Clothing: Inch, centimeter. *Hats:* Centimeter, inch. *Collars:* Centimeter, inch. *Underwear and Hosiery:* Centimeter, inch. *Shoes:* Centimeter, American numbers "An arbitrary measure equal to about 3/4 of a centimeter." *Gloves:* French numbers, American numbers. *Corsets:* Centimeter, inch. "The measures of the country from which the goods are imported are used."

For the Measurement of Land: Hectare, square kilometer, square league, sugar land in bahlocs (= 0.7 hectare), square meter.

Lumber and Timber: Square pie, metric.

By Carpenters and Other Woodworkers: Square pie, metric. "Some carpenters do actually work in English inches." *By Tailors and Seamstresses:* Centimeter, vara, yard, meter. *By Stone and Brick Masons:* Metric, fanega.

In Machine Shops: Libra, foot, metric.

In Contracts for Excavation of Ground: Metric. *In Mines and for Mining Products:* Metric. *In Smelting and for Smelter Products:* Metric. *Sizes of Pipe for Gas, Water, Sewers, Etc.:* Inch, metric.

In Ship and Boat Building: Metric, English. *Marine Measurements:* Metric English. "In navigation and geography miles are used; for the rest, metric."

Hay at Wholesale: Metric. *Grain at Wholesale:* Kilogram, metric quintal, fanega. *Meat at Wholesale:* Arroba, metric. *Root Crops at Wholesale:* Metric. *Coffee at Wholesale:* Metric quintal. *Milk, Butter and Cheese at Wholesale:* Metric.

Railway Tariff for Passengers and Freight (Load and Distance): Metric quintal, tonelada, kilometer, cubic meter. *Loads and Rates for City Transportation:* Metric quintal, kilogram. *Loads and Rates for Transportation by Muleback Across the Mountains:* Metric quintal. *Railway Track Gages and Length of Lines:* Meter, kilometer. *Railway Equipment* (*units used in the construction and repairing of locomotives, cars, etc.*): "Inches on English lines; metric units on German railway."

"Not only is it illegal to use any other weights and measures [than those of the metric system], but a merchant is subject to punishment even for having them in his possession. The importation of weights and measures other than the legal is also prohibited and as the authorities have destroyed the old ones wherever possible distinct progress toward the universal adoption of the new system has been made. In spite of the stringency of the laws the people at large, especially in the country, still cling to the old units in their every-day life and talk and think in terms of them."

"The people in the interior of the country are not at all accustomed to the metric system and always use the old system."

Venezuela "adopted" the metric system in 1857.

No. 1665

EFFICIENCY AND DEMOCRACY

By H. L. Gantt, New York, N. Y.
Member of the Society

The author raises the question as to why the word "efficiency" has fallen into disrepute in connection with industry when, as a matter of fact, efficiency, both individual and collective, is more needed now than ever before.

The reason seems plain — that in the past efficiency has been measured by the dollars acquired rather than by the goods produced.

The product of a factory should bear only the expense used to produce it. It cannot bear the expense of idle machinery which did not contribute to its production. Although the owner may feel that he is entitled to interest on money invested, even if not producing, it is coming to be understood that idle capital is no more entitled to wages than idle labor and the manufacturer should consider the elimination of idleness as essential and the production of goods at full capacity as a necessity. This is in accord with the democratic spirit of the times which demands that goods be produced in a way to benefit the community rather than those who control the industries.

WHY has the word efficiency, which should stand for so much, fallen into disrepute in this country? That it has fallen into disrepute cannot be gainsaid, both with the business man and the workman. We all recognize the importance of both individual and collective efficiency. This being true, there must have been some fatal error in the management of the campaign which at the end of twenty years has made the very name a byword.

2 It is not to be questioned that many men who have devoted their time to this subject have very much improved our industrial processes and the productivity of our manufacturing plants. Yet in the mind of the average business man or mechanic the term "efficiency engineer" raises a feeling of hostility.

3 Today we need efficiency, both individual and collective, to a far greater extent than we ever needed it before, yet it seems that we must do the work of promoting it under some other guise if we would really have it accepted and approved.

4 To some of us the reason seems plain, simply that we have in

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the past measured the "efficiency of our business" by the dollars acquired rather than by the goods produced. The efficiency engineer of the past has in too many cases devoted himself exclusively to making more efficient the business of securing dollars. In other words, he has served the business system primarily in the accumulation rather than in the production of wealth.

5 A business system bent on the accumulation rather than on the production of wealth, which would even curtail the production of wealth if thereby a larger measure could be brought into its own coffers, must needs finally run to the limit of its tether, and a method which makes more efficient such a system shortens the time which it has to run. An efficiency engineer who, consciously or unconsciously, served the business system in the exploitation of workmen, necessarily got the ill-will of the workman. He later got the ill-will of the business man, who found that the amount of wealth he could get by exploitation was strictly limited. I am not claiming that all efficiency engineers have done this, nor that even those who have done it have been conscious that they were producing a condition to which there must be an end. They were simply serving "business as usual," which puts more effort in harvesting the crop than in producing it.

6 When the great war broke out in 1914, it became evident to all those who gave it serious consideration that the production of goods for the benefit of the community, and not the production of wealth for the benefit of those who control the industries, was the task which had been set the nations engaged. It took England more than a year to learn this lesson, and we should have been fully prepared for it in 1917 when we were drawn into the maelstrom. That we were not prepared for it, and that many believed we could still continue business as usual, is now history. We have learned, however, that production for the benefit of the community was the only basis on which we could carry the war to a successful conclusion. This has been emphasized by the elimination of "non-essential" industries.

7 There is another reason why the term efficiency has been brought into disrepute. In the past our cost-keeping methods have always loaded on to the part of the shop which produced the goods the total expense of the shop, including the part that was idle. For instance, in a shop having two expensive machines, it was the habit to load on to the product the expense of both machines, whether the goods were produced by one or by both. Under

such conditions, if one machine did the work of two, the product was still charged with the expense of both, and the full benefit from the increased efficiency was not apparent to the owner, who saw only the saving in wages. He did not see the saving in plant. He did not comprehend clearly that if he doubled the output of his machine he could double the output of his plant without additional expense. In other words, that he was also making his capital twice as efficient. It is hard to see why he did not see this, except that the system of cost-keeping seemed designed to hide it. The term "efficiency" then seemed to have no connection with capital or investment, but only with labor.

8 Under such conditions there was but little inducement to the owner to make his machines produce more, and the reverse of an inducement to the workman, who was thereby laid off or saw his friend laid off. This fatal error which caused the opposition of the workman, and the lack of sympathy on the part of the employer, was evidently due to a false accounting system, which was devised to put all the burden of inefficiency on the workman.

9 When the great war started in 1914, and the wheels of industry slowed down to such an extent that it was impossible for the product turned out to bear the expense which had previously been distributed over a production three or four times as large, most people said, "These are extraordinary times; therefore we shall have to lay our cost system aside to keep till the war is over."

10 Some people, however, realized that a system which is not good for an emergency, when it is most needed, has something radically wrong about it, and set to work to find out what the flaw was, and this was the answer they arrived at:

11 The product of a factory must bear only the expense used to produce it. It cannot bear the expense of idle machinery which did not contribute to its production. This statement is such a radical departure from the ordinary cost-keeping system that it produces a shock to the business man who has a theory that he must somehow or other get back all of his expenses. He seems to feel that he is entitled to interest on all the money he has invested, whether it produces anything or not. Under such conditions he is not seriously worried so long as he can sell his product for a price high enough to give him the profit he considers himself entitled to.

12 Some of the keener business men, however, have seen the flaw in this argument, and have realized that idle capital is no more entitled to wages than idle labor, and have begun seriously to study

their plants to find out how they can use them to their full capacity. The result of this investigation is twofold:

a It does not result in laying off men, but gives employment to more men, which secures the good-will of the worker

b It not only reduces the expense of maintaining machinery in idleness, but turns out a greater product from which revenue is gotten.

13 Some would say that this is a beautiful theory, but it doesn't work that way. I answer unhesitatingly, after more than three years' trial, that it does work that way and that none of those people who have adopted it would for a moment think of going back to the antiquated method of cost-keeping which they have given up.

14 The keynote of such a system is the elimination of idleness and the production of goods. Moreover, there is no antagonism in such a scheme between employer and employee, for each gets the reward for what he does.

15 To the conservatives this would seem almost revolutionary, and fraught with consequences of which they cannot see the end, but it is democratic and absolutely in harmony with the patriotic doctrine which is being preached. It enables us to change automatically our slogan of "business as usual" into "business for production and victory."

16 In a few words, then, if we will eliminate our false cost-keeping methods, and put in those that are correct, we shall not only benefit both employer and employee, but go a long way toward the democratization of industry.

In presenting his paper the author pointed out that on the battle front war was competition in destruction, while behind the lines it was competition in production. He quoted Prof. C. R. Mann as saying that war was eight-tenths engineering, and that the engineer was the great production factor in the commonwealth. That through the efforts of engineers the war had been prolonged four years, and that it was certainly they who had won it. The next thing was to find out what part the engineer was to play in *keeping the war won*.

He then led up to the point where he hoped the engineer would be a more influential factor in the conduct of national affairs than heretofore, because he had demonstrated that *he knows what to do*

nd how to do it. He showed that when the war broke out leading usiness men offered their services at Washington, but found that ıeir usual methods of doing business did not produce the required ıips and shells, for they had been trained to operate for profits ıstead of for production. That engineers had attacked the problem ı a different and successful way, he said, would be demonstrated uring the discussion of his paper.

To supply the mechanical needs growing out of the war in suffi-ient quantity and in short time, progress charts had been compiled y engineers to show graphically the rate of production. These harts were used extensively by the engineering department of the Iavy in the construction of shipyards, as well as in various large ıanufacturing establishments.

When the war broke out in Europe every one there realized the ecessity for greater production per capita, and it was the same in the Inited States. We should continue to improve our efficiency, and o machines should be allowed to be idle, so we should help those eople who could do but little. If we did this we should also have ıe coöperation of the workman.

The system of keeping track of work done by means of the charts hich he had devised would be illustrated by a number of speakers ho would show its successful application in the Ordnance Depart-ıent, the Shipping Board, Emergency Fleet Corporation, and in umerous other places and in private plants. He said that while ıe worker was busy studying efficiency, the engineer should turn is attention to the study of idleness.

DISCUSSION

WALLACE CLARK,[1] spoke of the task confronting the U. S. Ship-ing Board when it devolved upon that body to supervise ships afloat nd building. The problem was to get troops to France and to bring ı the United States food and raw materials. The former was done y the U. S. Army, and the latter by the Shipping Board. This oard had first ascertained what was needed at given times. Then had listed its ships, which aggregated about 12,000, and it was ere that the efficiency chart was of such service, inasmuch as it fforded a graphical record showing in all required detail the daily ıovement of every ship, and made it possible to estimate beforehand

[1] 2905 Singer Building, New York, N. Y.

the available carrying capacity in any direction for several months ahead.

Mr. Clark had a few typical charts projected on the screen, the first showing the rate of import of nitrate from Chile to this country. Of this, 800,000 tons, or more than half the output, was called for in the course of the year. To this work 175 ships were detailed. Charts 11 in. by 17 in. in size were ruled up in such a way that the vertical columns represented days, weeks and months, proceeding toward the right. The descriptive items for the spaces between the horizontal rulings were placed along the left-hand margin. From these toward the right were drawn heavy lines, the length indicating how near up to date the deliveries were. The space represented both the time and the amount to be delivered in that time; the line represented the actual deliveries. In the case of the ship record there was one horizontal space for each ship. From the record could be told the weight of cargo, how long it took each ship to make a round trip, and when it could be expected to arrive. At the end of each month the various burdens could be added up and note taken of the progress made. It was possible to observe from these charts the over-supply as well as the deficiency of about a hundred necessary commodities, and this furnished the required means of regulating the activity of the ships.

Another slide showed a similar chart applied to recording the progress made on certain field-artillery mechanisms. Each mechanism had to go through 67 different operations in manufacture. The desired output was 10 mechanisms a day, and if the horizontal lines or bars on the chart were all of equal length, that would mean 70 mechanisms completed each 7-day week. However, the charts showed that some operations were proceeding at the proper rate, some were ahead, while others lagged behind, their lines being short, and therefore demanded special effort in order to meet promised deliveries of completed sets.

A. T. Clarke[1] exhibited slides of charts showing the movements of over 7500 ships, 150 of which were employed in supplying coal from Chesapeake points to New England ports. Instead of a single horizontal bar, a series of circles and special characters were placed in the horizontal column for each ship, at the required dates. A circle represented the face of a clock, a closed circle denoting a full shift of 10 hours' idleness. A symbol inside of a complete or an

[1] Brighton Mills, Passaic, N. J.

incomplete circle gave the reason for any idleness. Thus, a wavy dash meant adverse tides or bad weather.

The cards were 11 in. by 17 in., each side for six months. For each month there were six horizontal lines, A to F. The dotted line "A" would show at some date a forward inverted "L," indicating the date the ship arrived at port. Some days later, on the same level, there would appear an inverted "L," turned the opposite way, indicating arrival at the distant port. The distance between brackets indicated the time spent in port. The ship's name and the tons of coal or other load carried were marked in the open space between the brackets. After the second bracket was written the name of the port bound for. While in port a separate symbol signified "discharging cargo," another "discharging ballast"; the relative position of the symbol indicating whether the work had been done by day shift or night shift.

On the chart was also indicated the time consumed in discharging cargo, also how the ship was held up waiting for dock accommodation, and whether it had to undergo repairs which might or might not have interfered with loading or discharging. At the end of the month a cost statement could be prepared of the transportation cost per ton over this route. A new chart was then made having a vertical column for each fleet or group of ships in any given trade. The height of this column represented the total cost, which was made up of the various items entering into the cost of transportation. This showed the performance of each fleet, the shortest column indicating the lowest cost per ton carried.

W. H. Blakeman [1] submitted a written discussion in which he said that one of the greatest handicaps in shipbuilding for many years had been the lack of progress in planning and scheduling and in general foresight as compared with the improvement in production facilities. He had worked out a simple plan by which the management of a yard could see how its schedule was being lived up to, or compare what had been done with that should have been done.

This was shown by means of a graphic straight-line chart which gave the maximum information in a minimum space, and which he had found much superior to charts employing curves.

Vertical columns on the chart represented days and the spaces between the horizontal rulings applied to the various items of work. Along these horizontals were marked various characters and symbols

[1] Union Shipbuilding Co., P.O. Box 475, Baltimore, Md.

showing the status of the work at the date they appeared. The rate of receipt of structural material was thus apparent from the charts, the rate of erection, rivet driving, installation of equipment, etc. The Emergency Fleet Corporation had been instrumental in having this simple and effective chart system introduced at 90 per cent of all the shipyards to which it had been presented.

S. B. BARROWS,[1] described and had shown on the screen a number of the Gantt type of progress charts which had proved of great value in systematizing the proper rate of production of completed airplanes.

JAMES J. REYNOLDS showed charts devised, with the assistance of Mr. Gantt, for accelerating the production of artillery ammunition at the Frankford Arsenal. Blueprints of these charts were regularly sent to Washington and information thus imparted without entailing the vast amount of correspondence previously required.

H. J. SWALLOW,[2] of the Emergency Fleet Corporation, exhibited a number of record charts that had been found necessary for procuring in due time the thousands of articles required in the completion of ships.

CAPT. CHARLES E. DAVIES[3] illustrated the use of the Gantt progress charts as applied to the manufacture of fuses. He stated that the charts had been of great service in registering the rate of production and the relative efficiency of the departments.

JOHN E. MULLANEY showed charts used for greatly facilitating the production of complete machines, and indicating at once when a portion of the equipment was not producing its rated output.

FRANK B. GILBRETH moved that Mr. Gantt be asked to submit to the Society a general progress chart for the use of all businesses embodying his latest ideas — a chart that could be used as a standard, which motion was put to vote and duly carried.

WALTER N. POLAKOV said that the old business system had involved great wastes of life, health, time and natural resources, but as it had succeeded in making profits out of these wastes, efficiency in the past had not become a part of business policy. If we were

[1] De Laval Steam Turbine Works, Trenton, N. J.
[2] Celluloid Co., Newark, N. J.
[3] Remington Typewriter Works, Ilion, N. Y.

now to return to that system the cause for which our soldiers had fought would be lost, for it was certainly not democracy to waste arbitrarily our resources and make the people pay for losses of destruction brought about by the incompetency of some and legalized by the blindness of others. The war had definitely changed the old standards and in his opinion the task before engineers was threefold: (1) They should lead in extending credit and authority to those who know how to do things and whose records show that they have done them. (2) In industrial relations they should adopt the principle of "no secret agreements," so that workmen would know what the management did, and one manufacturer would know what the others were doing, and that the people would know what it cost to produce commodities. (3) They should see that all natural resources are controlled just as are the public funds, and not allow needless waste, for the forests and mineral resources, particularly fuel, are the foundation of national prosperity. As an organized body, engineers should set an example of a government by facts.

THE AUTHOR, in closing, said that the reason so many performance charts from various classes of plants had been shown was for the purpose of proving their wide applicability.

After the war had broken out he had gone from the Frankford Arsenal to Washington to see General Crozier to discuss questions of organization. His method of charting production appealed to the General, and it was introduced at once, so that by November 1917 about three-quarters of the production in the Ordnance Department was charted by it in detail. In addition the method was welcomed by a large number of plants throughout the country, as had been just shown.

It developed later that in November 1917 Professor Schneider, Dean of the University of Cincinnati, had also been invited to Washington by General Crozier to confer on labor problems. Early in December the Dean handed the author a copy of his report made early in December 1917 to General Wheeler, at that time General Crozier's first assistant, in which he had recommended for adoption by the entire War Department the production charts already successfully applied by the Ordnance Department. Just about that time Congress met and criticism developed. Business men from all over the country went to Washington to help straighten out matters. These men were mainly financiers and salesmen not acquainted with production. They did not understand that Wash-

ington's problem was one of production and hence that an organization such as General Crozier's was built primarily for production. The organizations which they understood were built primarily for profit; but the country did not need profits, but goods.

The result was that General Crozier was ousted and his whole plan of organization of the Ordnance Department went to pieces.

Although General Crozier's plans had been thus disrupted by his successor, a start on the same lines had already been made in the U. S. Shipping Board, and from there the methods gradually spread to other Government departments, including finally the arsenals. Had the original plans of General Crozier been carried out, the author believed there would have resulted less trouble in the supply of ordnance and many lives lost in France would have been saved.

No. 1666

PRESENT PRACTICE IN THREAD-GAGE MAKING

By Frank O. Wells, Greenfield, Mass.
Member of the Society

The author describes the difficulties experienced by manufacturers of thread gages in their efforts to maintain accuracy and standardization and, at the same time, meet the present demands of increased production.

The process of cutting threads in the lathe requires expert manipulation to be successful. The errors in lead screw should be corrected and a good cutting tool correctly held is essential. Approved methods of thread lapping, grinding and testing are described.

The question of tolerances is important. An unreasonable and useless accuracy of gage tolerance complicates the making and increases the cost of thread gages. The author recommends a set of values for medium tolerances. The figures are not too close and are offered as applicable in most practical cases.

THE manufacture of thread gages brings in all the difficulties of any thread product, multiplied according to the degree of accuracy required. The usual methods of making threads must therefore be refined and improved, and at the same time standardized for manufacturing purposes.

2 To maintain and even to increase the accuracy and standardization of product, as is specially demanded, is no easy task, but it is being done by paying careful attention to the troublesome points.

CORRECTING LEAD SCREW

3 Given the blank for a thread plug gage, centered and turned, the real trouble begins with chasing the thread. A lead screw must be as accurate as the product to be turned out by it. Errors in lead screws are of two kinds — errors in lead over a considerable length of the screw, and local errors from thread to thread. If, as is often the case, the lead screw was made for ordinary work

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instead of for precision work, its lead or pitch will be irregular to a greater or less extent. The total deviation of the lead screw must then be determined, and the lead-adjusting attachment (Fig. 1) set to give the correct compensation.

4 The thread cut on a soft gage must always be slightly different from standard or finished pitch by an amount equal to the expected change during hardening. This correction must also be made by the lead variator.

5 Adjusting attachments like that in Fig. 1 compensate fairly well for errors in the lead screw which are constant at any part of

FIG. 1 LEAD-ADJUSTING ATTACHMENT FOR LATHE

its length. They do not, however, take care of the trouble of "high and low" threads.

CHASING TOOLS

6 Given a fairly good lead screw, the next mechanical necessity is a good cutting tool correctly held. Such tools, with removable cutting blades, are shown in Figs. 2 and 3, one for inside and the other for outside chasing. The fixture for grinding the tool for outside chasing is also shown in Fig. 4.

7 The threading-tool blades in Figs. 2 and 3 are made to cut on a 20-deg. clearance angle. This clearance angle makes the actual included angle of the tool blade, normal to the straigh-

ıtting edge of the tool blade, 63 deg. and 8 min. The thread groove ut by a proper threading tool should preferably be from 15 to 30

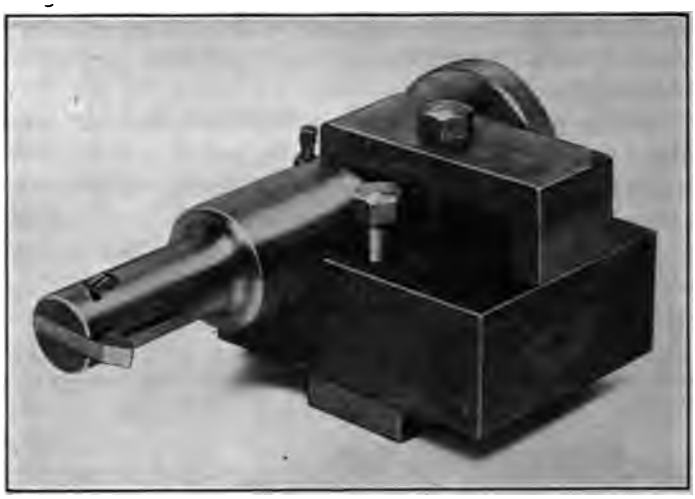


FIG 2 TOOL FOR INSIDE CHASING

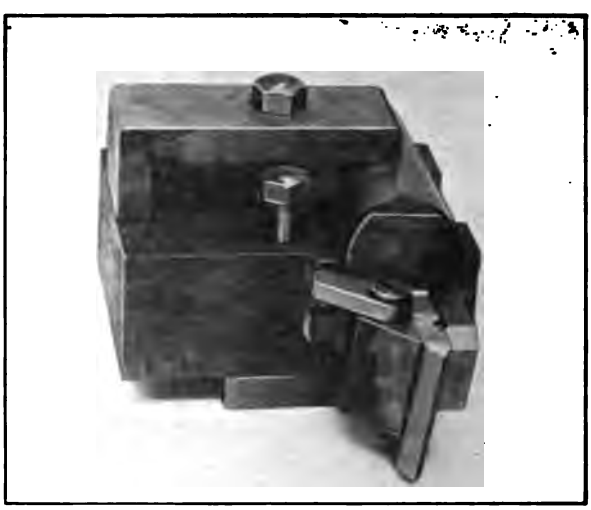


FIG. 3 TOOL FOR OUTSIDE CHASING

in. sharp in order to facilitate the lapping operation. For all dinary U. S. standard pitches the threading-tool blade is set ith its axis at right angles to the axis of the gage. It is only for

Acme or similar very coarse thread work that it is necessary to incline the threading blade to a line parallel to the helix angle of the gage being threaded. When this helix angle is very steep it is necessary to modify the included angle of the cutting edge so that the angle cut, on a plane with the axis of the gage, will be as required by specification.

8 There is great difficulty in getting men who are good at threading. Good threaders seem to be born, not made. The work requires a combination of brain, mechanical ability, sensitive touch and, above all, patience. Some otherwise good mechanics can never make good threaders. A green man with a phlegmatic temperament is a likely candidate for development. Few girls can be developed into handling fine threading — it requires just a little

Fig. 4 Fixture to Sharpen Tools for Outside Chasing

more mechanical sense than any appreciable number have had time to acquire. The Government should be careful about taking men from gage-threading lathes, especially when on the same day another branch of the Government may send an urgent appeal to increase or even double the production of gages.

9 With good men, fair lathes, the best cutting tools and the exercise of constant care, it is possible to get threading of gages down to a limit of accuracy which falls within the variations due to hardening. If a perfect contour of thread and perfect angle, lead and walls could be secured when threading in a lathe, it would not be necessary to leave more than 0.0002 to 0.0006 in. oversize, knowing that hardening would increase this to from 0.0015 to 0.0020 in. Due to irregular swelling, shrinking and warping from thread

to thread in the hardening, however, a certain amount of stock must be left on so that no point of the gage will be distorted outside of the limits of the metal. If the thread, for instance, should take a quirk to the right so that its center line was displaced at the top of the crest by 0.0009 in. and the metal had been left 0.0015 in. larger than finished size, the reduction to finish could be made and still leave a complete crest.

10 Since a margin must be left for the vagaries of hardening, the necessary tolerance in lathe threading can probably be obtained by the precautions noted.

11 Formerly it was common practice to make the outside diameter of limit plug thread gages uniformly oversize in direct proportion to the oversize of pitch diameter. This practice was wrong because of the danger of the maximum or not-go plug forming contact on the outside diameter of the tapped hole and yet giving no indication as to the actual size of hole on the pitch diameter or the thread walls.

12 In view of the fact that both the go and not-go plugs are over basic or maximum screw size, they should both be provided with a minus tolerance below the minimum tapped-hole outside diameter, in order to assure that the gage will positively check the angular diameter. This can be done since there is no danger of the screws forming contact with the outside diameter of the tapped hole.

SCHEDULING ORDERS BY GROUPS

13 One great difficulty in manufacturing for Government or priority war orders marked "rush," is that the orders cannot be scheduled in the most efficient and sensible way, and in the end the speediest way. There is really no reason why all orders calling for the same outside diameter and same length over all should not be grouped in turning, and so enough blanks run through to cover orders for various pitches. Again, in the thread-lathe room gages of the same number of threads per inch, but differing by one or two thousandths in pitch diameter, could be chased out as members of the same group. They could be run through with one set-up of the lathe, and save on the average 30 per cent of the cost of the same orders ungrouped. Since small similar orders like this, varying only by differentials, constitute about half of the output of the gage factory, such a grouping would save about one-sixth of all the expense of the department as conducted under present methods.

14 The reason that this cannot be done now is that when a rush priority order for, say, two $\frac{5}{16}$-in. 24-thread gages comes in it has to be routed, started, put through, and finished at once. Then, if the next A1 priority order is for eight 3-in. 8-thread gages, these must immediately follow, without waiting for another small size which might be done with the same setting of the lathe and which perhaps is equally important but which happened to come in a little later. If a batch of the same size were put through all at once, so much time would really be gained that the succeeding orders meanwhile sent in by the Government would be done considerably sooner, in the long run, and the Government be much the gainer in aggregate time.

15 Accurate micrometers or gages should be constantly used over all parts of the thread while in process, and accurate lead testers and gages should be constantly on hand in the workroom itself.

HARDENING

16 The hardening question has always been the bane of threading. A series of tests made some time ago by laboratories of manufacturing firms throughout the country demonstrated that threading on taps and dies can be gotten down to any reasonable limit of accuracy, but that this is not true of hardening. The inaccuracies in taps and dies, manufactured as is necessary by quantity methods, in general appear after hardening and are not present in the soft product. The same is true of gage threads, only of course the error involved is proportionally of more importance on such fine work.

17 During the process of hardening there is in the majority of cases an increase or swelling in diameter and a shrinkage in length, resulting in a shortening of lead, but the extent to which this occurs will vary in different pieces. Even with the quenching bath and the temperature of furnace kept uniform, the swelling in diameter in one set of duplicate samples of about an inch in diameter varied from 0.0008 to 0.0024 in. and the lead error varied from 0.0005 to 0.0025 in.

18 In general, the best hardening method for gages can be described as follows: Ascertain the lowest heat which will give the proper depth of carbonization, in a reasonable time, and next ascertain the heat at which the gage will properly harden upon quenching, and maintain these two features within the closest possible limits of uniformity.

LAPPING

19 If the lathe work has been done correctly and the hardening without distortion the thread can be smoothed to a finish by lapping off not much more than 0.0002 in. Under ideal conditions, therefore, this would be the amount of oversize that would be specified for gages coming into the lapping room. A much neater and quicker job of cleaning the thread to size could then be done, and the cost of lapping would go down.

20 However, not only excessive oversizes but distorted pieces come into the lapping room. The lapping process can to a certain extent take out these inequalities as well as smooth the surface of the chased thread. It should be emphasized, however, that the lapping process is not for this purpose and that every correction that has to be made in the lapping costs excessively and slows up the other work. Lapping should not be depended upon to do correcting, but the threading should be in correct shape before reaching the lapping room.

21 If the angle of the thread is slightly too wide or narrow or tipped to one side, a skillful lapper can correct it. If the lead is a trifle too long or short, the lap can take it back to the proper length, by wearing the surface off on one side or the other of each thread. If the pitch diameter is too large, it can be worn down. But, of course, there is a limit to the amount that can be worn off by hand-applied friction, using the general form of thread as a guide, and still retain an accurate contour. It is practicable to take off a total of 0.0015 by lapping without spoiling the shape, if it is done carefully on only one gage. Therefore, allowing part of the overstock for smoothing, if the errors are not cumulative or all in the same direction, it is possible in lapping out 0.0015 in. oversize in diameter, to take care of an error of 0.0005 in. in lead and 15 min. one way or the other in the angle.

22 Two forms of lapping machine for thread plug gages are shown in Figs. 5 and 6. The machine shown in Fig. 5 is for lapping parallel thread gages. The machine shown in Fig. 6 is for lapping taper threads, such as pipe threads.

23 Soft steel laps are most easily chased out smoothly and are the most durable. Some prefer cast-iron laps, however. The lap is an important part of the work; it must, of course, be threaded more accurately than the gage which it is to correct. Flour of emery makes the most satisfactory lapping medium for thread gages, particularly for lapping the thread walls.

FIG. 5 THREAD PLUG GAGE LAPPING MACHINE

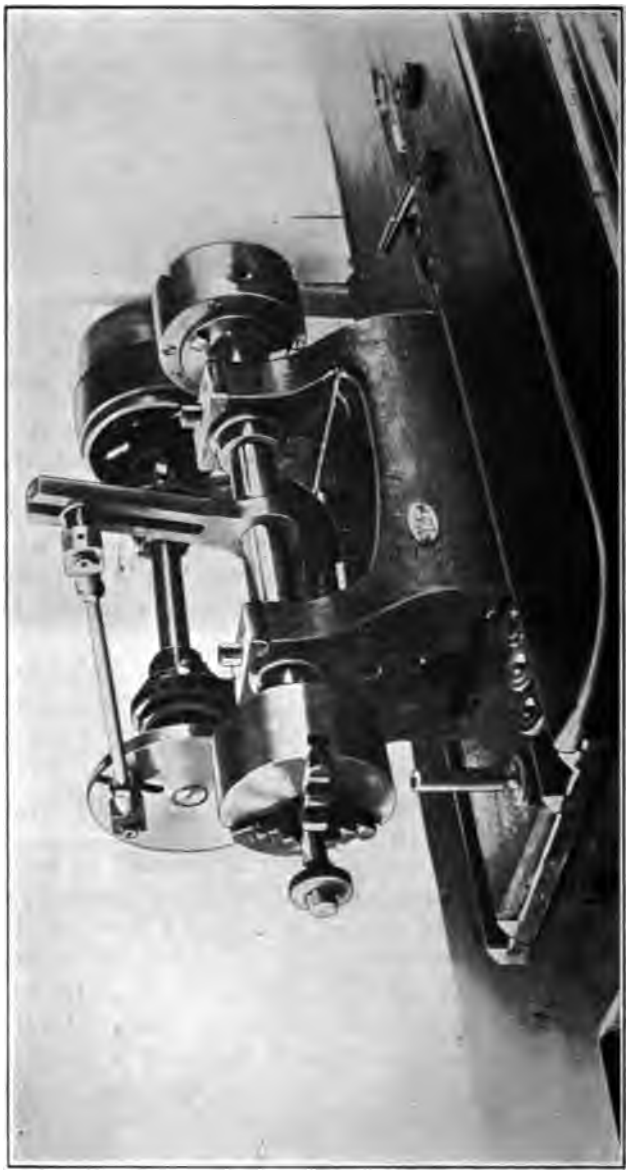


FIG. 6 DOUBLE LAPPING MACHINE

24 In view of the fact that a thread gage can be no better than the lap which finished it, it stands to reason that laps must be made just as accurately as is possible, and therefore in order to get the most possible use out of a lap it is essential that the threaded work which is ultimately to be lapped be also made as carefully and accurately as possibly can be done. It is not profitable to leave any more corrective work for the lap to do than can possibly be avoided. As the lap is of soft material, but very little pressure applied in a false direction will be sufficient to ruin it. Girls may be used on lapping if ones with level heads and the requisite sense of touch are selected.

25 Inspection instruments, including a sufficient number of gages, a projection apparatus and micrometers, should be on hand in the lapping room for the use of all employees, who should be trained to use them and to interpret the measurements.

GRINDING THREADS

26 Grinding out the inaccuracies in the large-size threads is much more expeditious and cheaper than lapping them out. The problem of grinding threads becomes difficult, costly and impracticable, however, below a certain minimum size, in general, for the following reasons:

27 In grinding out a V-thread as near as practicable down to the theoretical triangular point, as is done in thread gages, there is intensified friction upon the delicate edge of the wheel and it wears away very quickly. It could not be used at all were it not for the fact that the extreme edge of the wheel does not have to be maintained absolutely as an acute angle.

28 Although the profile of the gage thread must be kept accurately straight along seven-eighths of the wall, the remaining eighth in the extreme root can be allowed to become a little rounded off, since it will not engage any part of the thread but will be used as a clearance space. Now an eighth of a large pitch on a large diameter gives the wheel edge considerable margin for wear. The absolute length of this margin decreases toward the point in proportion as the pitch from thread to thread decreases, and soon the point is reached where the allowable eighth margin at the edge of the wheel wears away too fast for practicable replacement of wheels. One wheel should do at least one complete gage before needing to be trued at all, since the wheel cannot be taken out and put back in the same place with any success. This margin of wear on the

wheel is now generally reached at a pitch of 30 threads to the inch.

29 On the average, the best thread grinding wheel is about No. 150.H, as we find in our own work. For the grinding process, from 0.003 in. to 0.008 in. of stock should be left on a thread gage to enable the operative to set his wheel in the center of the thread by adjustment and trial, and also permit him to correct inequalities in lead, angle, or diameter due to hardening.

30 Out of 0.003 in. of stock he can increase or decrease the lead by 0.001 in., if the angle is already correct. Similar corrections in the other dimensions may be effected.

31 All work coming from the grinding room is then lapped for a final finish.

INSPECTION

32 Inspection in gage manufacture assumes an importance that it has in hardly any other branch of work. This is still more true of thread gages. The many dimensions that are on an apparently simple product require close attention to each separately and to all together.

33 To test the lead the Bingham Powell machine is a good instrument. The method of holding the gage, the micrometer wheel and vernier and the electric telltale which indicates proper contact of the measuring fingers and the thread, are shown in Fig. 7.

34 A testing machine fitted up with a slide rest in parallel so that only two wires are necessary is good for measuring pitch diameter, by aid of a micrometer reading. This machine is provided with two removable tables, one for large work and one for small, as shown in Fig. 8. To test the micrometer a set of Johansson blocks should be on hand, and finally to resolve immediately any doubts one might have as to the accuracy of a particular block or measurement, a good measuring machine should be on hand. Tenths and hundredths of thousandths are elusive things, almost imaginary, impalpable and invisible. A man traveling down among them and coming upon any doubt in his own mind as to his exact location is like a man lost in a woods, and it is necessary to follow the old prescription of wise travelers to always carry two compasses or two watches. If one is assailed by a sudden doubt that one may be wrong, look at the other. If they both say the same thing, one feels that it is a million to one that they are both all right, and can go ahead.

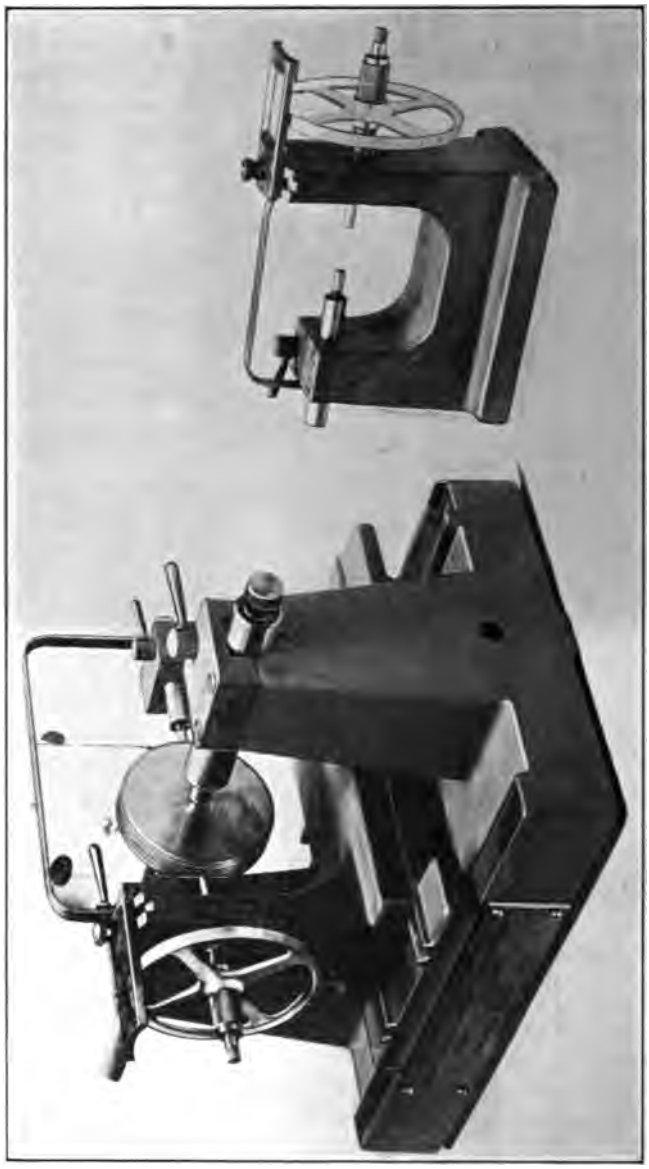


FIG. 8 MACHINE FOR TESTING PITCH

FIG. 9 PROJECTION LANTERN FOR CHECKING SILHOUETTE OF THREAD

35 To examine the contour of the thread, the angle and the root, crest, and smoothness of wall, a projection machine as shown in Fig. 9 is the only proper thing. It instantly gives an enlarged silhouette of the thread, which speaks for itself, for the profile can be compared with pattern gages held upon the screen as in the illustration. The silhouette can also be photographed for transmission to a customer by inserting a film or plate instead of the

FIG. 10 PROJECTION MACHINE FOR CHECKING CONTOUR OF THREAD

ground glass. Mechanism is provided for holding the gage, for focusing it and for turning it to the helix angle so as to get a symmetrical projection of the walls.

36 Sulphur casts of female threads can be taken in quick time and at small cost, and the contour examined in the same quick way. The method of pouring the melted sulphur into a molding frame held against part of the thread so as to get enough of it to give contour and lead, is shown in Fig. 11.

TOLERANCE ON GAGES

37 One great difficulty with the business of manufacturing thread gages is the unreasonable and useless accuracy of gage tolerance and wear allowance sometimes requested by purchasing firms. When a tolerance of 0.0002 in. is set on a gage specification, it should mean that the customer's tolerance on product is as close as 0.001 in. If the purchaser's manufacturing tolerance is any broader than that, there is no use in keeping the gage so close. A 0.0002 in. error would be lost in the comparison. In order to facili-

FIG. 11 MACHINE FOR INSPECTING FEMALE THREADS

tate the making and to lessen the cost of thread gages, it is well to allow quite liberal tolerances in their manufacture, and we recommend the following as being applicable for most cases where medium tolerances are allowed on product:

38 From 4 to 6 pitch allow a tolerance of 0.0006 in.; from 7 to 18 pitch allow a tolerance of 0.0004 in.; from 20 to 28 pitch allow a tolerance of 0.0003 in.; from 30 to 80 pitch allow a tolerance of 0.0002 in.

39 The foregoing applies to master gages. For inspection gages the tolerances would be slightly wider, and would begin where the

master inspection gage tolerances leave off. These would be as follows:

40 From 4 to 6 pitch a tolerance of 0.0009 in.; from 7 to 10 pitch a tolerance of 0.0006 in.; from 11 to 18 pitch a tolerance of 0.0004 in.; from 20 to 28 pitch a tolerance of 0.0003 in.; from 30 to 40 pitch a tolerance of 0.0003 in.; from 44 to 80 pitch a tolerance of 0.0002 in.

41 All of the foregoing tolerances would be applied plus in the case of go male gages and not-go female gages; and minus on not-go male and go female thread gages.

42 The plus and minus tolerances given apply to pitch diameters of all thread gages and also to root or core diameters of templets or female thread gages.

43 The maximum, or go, templet gage represents the maximum or basic screw and its manufacturing tolerances should be minus on pitch diameter and root diameter. The minimum, or not-go, templet should be made to plus tolerances with an extra plus allowance on the root diameter, which will insure this gage really checking the effective size of the screw.

44 There is no need for a manufacturer to require every gage made to the finest point possible if he would not want to hold himself to the corresponding tolerance in his own product. People sometimes do not stop to think that to measure down to 0.0001 in. one must use exquisite care as to cleanliness, vibration and control of temperature between master and part.

45 The wear and adjustment tolerance on a gage should be coarse or fine on a sliding scale according to the manufacturer's tolerance on his product. If a tolerance of 0.0002 in. is really necessary, all well and good; but the cost of the gage will be in proportion to the tolerance allowed.

No. 1667

THE MEASUREMENT OF THREAD GAGES

By H. L. Van Keuren, Washington, D. C.
Associate-Member of the Society

In this paper the author describes the apparatus used and the methods employed at the Bureau of Standards for the measurement of thread gages. This is of particular interest to the members of the Society, inasmuch as through the Gage Committee it was recommended that the Bureau of Standards be designated as the official place for the certification of gages for the various departments of the Federal Government.

In the measurement of both plug thread gages and ring thread gages, there are five distinct operations, namely:

a The measurement of pitch or lead
b The measurement of form and angle of thread
c The measurement of core diameter
d The measurement of full diameter
e The measurement of effective diameter.

The optical pitch-measuring machines designed and constructed by the Bureau of Standards after the original design by the National Physical Laboratory of Great Britain, have been found to be very well adapted for the rapid measurement of working and inspection thread gages, as well as for the precision measurement of master thread gages, and details are given of their design and operation.

The Bureau of Standards' projection lantern, used for the examination of the form and included angle of thread gages is also described and its convenience and accuracy of operation are pointed out.

Complete as well as approximate general formulæ for the computation of effective diameters from measurements taken by the three-wire method for 60-deg. United States standard threads, 55-deg. Whitworth threads, 53-deg. 8-min. Lowenhertz threads, and other threads of a similar nature, are given. There is also included a simplified formula for 60-deg. threads which will be found more convenient than the corresponding formula as given in most engineering handbooks.

Various devices and accessories used in the measurement of pitch, angle and form of ring thread gages are described, and in addition there is discussed the measurement of the effective diameter of ring thread gages by the use of a check gage and also by the three-ball method, which is similar to the three-wire method.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

IN the production, test and use of thread gages there has been during the past few years considerable development in the methods employed and the facilities available both in manufacturing plants producing thread products and in the inspection departments of the United States Government. At the Bureau of Standards extensive developments have been made in the design and construction of special apparatus and in the preparation of technical data and formulæ for the test and measurement of thread gages.

2 Many of the members of this Society will recall that through the Gage Committee it was recommended that there be a central place for the certification of all master gages. The Committee further recommended that inasmuch as Congress has provided the Bureau of Standards with a fund for the certification of gages; and furthermore, inasmuch as the Bureau of Standards was organized and prepared to handle promptly the test of all master gages, the Bureau be designated as the official place for the certification and test of gages for the various departments of the Federal Government. It is of particular interest, therefore, that the Society should know the developments that have taken place along the lines recommended and in this connection the present paper is prepared.

3 It will be realized that there is quite a difference in the procedure employed in various gage-making shops, inspection organizations and Government laboratories, and that to give a résumé of all the methods used by various authorities would be quite out of the scope of this paper. The methods given herein, therefore, are restricted to those which are in use at the Bureau of Standards at the present time.

4 In England the standardization of thread gages has been carried to considerable refinement by the National Physical Laboratory and by the Engineering Standards Committee of Great Britain, an organization which coöperates with the National Physical Laboratory. In May 1917 the Bureau of Standards was fortunate in being able to confer at Washington with Mr. C. H. Vidal, a representative of the National Physical Laboratory, from whom drawings were obtained of the various pieces of apparatus used by the National Physical Laboratory for testing thread gages. Needless to say, the Bureau was quick to adopt the practices which had been found useful by the National Physical Laboratory, and although apparatus such as the projection lantern and pitch-measuring machine had been ordered from the National Physical Laboratory, immediate work was instituted in the construction of similar ma-

chines, and long before gages were being produced in any quantities for military purposes, the necessary apparatus was available.

GENERAL PROCEDURE EMPLOYED

5 In the testing of gages there are two main considerations, namely accuracy and rapidity. While ordinarily the test of a thread gage is not a precision measurement, the more accurate the methods of testing are, the less time and precaution need be taken by the operator. All apparatus should be such that the constant errors and variable errors of observation are relatively small as compared with the permissible tolerances on the gage to be tested. A great many discussions arise due to the fact that assertions will be made that a particular gage is within 0.0001 in. or 0.0002 in., when actually two men will differ in making measurements on the gage by several times that amount, due to errors in instrument or method.

6 After precautions are taken for the reduction of personnel errors of observation and errors in instruments, gross errors are often made in the setting down of figures and in making computations. In this connection a system is in use at the Bureau of Standards in which a gage is tested by one man on a given piece of apparatus and then checked by a different operator who uses different instruments and oftentimes different methods. This checking method is most effective in the way of preventing mistakes and establishing the value of a given machine or method.

7 As in any production problem, rapidity may be secured by systematizing the routine of test; by the elimination of small delays; and by the introduction of methods and apparatus especially designed for rapid operation without a sacrifice of the accuracy required.

MEASUREMENT OF PLUG THREAD GAGES

8 In discussing the details of thread-gage measurement, reference will be made first to male threads, as the explanation of the procedure in this case is not as complicated as in the case of female threads.

9 There are five distinct operations in the measurement of a plug thread gage: namely,

a The measurement of pitch or lead
b The measurement of form and angle of thread
c The measurement of core diameter
d The measurement of full diameter
e The measurement of effective diameter.

10 There are numerous commercial devices designed to serve as comparators for comparing one screw with a standard and thus determine the error in pitch. These comparators are usually designed to measure the pitch over an interval of $\frac{1}{4}$, $\frac{1}{2}$ or 1 in.

MEASUREMENT OF PITCH

11 After trying various commercial machines for measuring pitch, the machine adopted for this purpose by the Bureau of Standards was of a design similar to that of the National Physical Laboratory of Great Britain. This machine, shown in Fig. 1, is

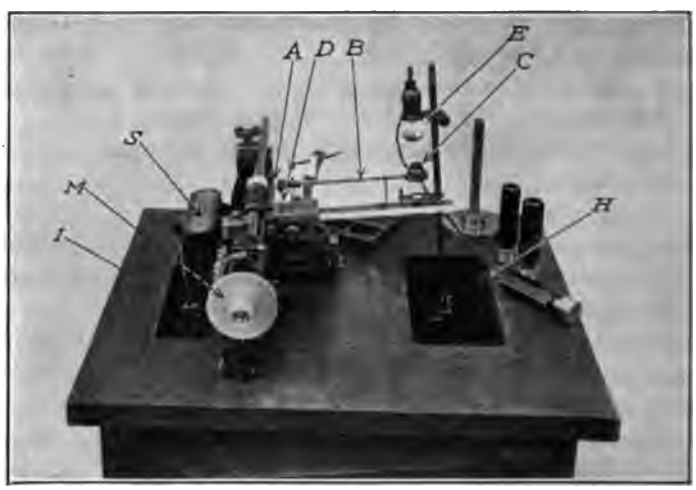


FIG. 1 PITCH-MEASURING MACHINE ADOPTED BY THE BUREAU OF STANDARDS

capable of making direct measurements of pitch, and furthermore is not limited to any one thread interval, but determinations of the lead between any two threads may be made. About twelve of these machines have been constructed and are in use at the various branch laboratories of the Bureau of Standards. There are incorporated in these machines special micrometer screws designed and constructed by Dr. J. A. Anderson, who is associated with Mount Wilson Solar Observatory, Pasadena, Cal. These micrometer screws are provided with aluminum heads which are graduated directly to 0.0001 in. and the screws have straight-line calibration curves to within 0.00002 in. They are therefore very well suited for the purpose for which they are used.

12 The operation of the Bureau of Standards pitch-measuring machine may best be explained by referring to Fig. 1, as follows: A ball-pointed stylus A rests in the thread to be measured. This is carried at the end of a floating arm B which at the other end carries a lens C. The arm B is supported by a flexible, flat steel spring D, and the movable support upon which the spring is carried is so adjusted that the spring D exerts a slight pressure on the floating arm B, which tends to cause the stylus A to rest firmly against the flanks of the thread. When the stylus is resting evenly on both flanks of the thread the lens C is directly beneath the lamp E and the image of the straight filament in the lamp E is projected by the lens C downward to a prism H, thence under the machine to the prism I, from where it is reflected to the screen S. When the image of the filament coincides with a reference line on the screen S, the reading of the micrometer M is recorded. The turning of the micrometer head M causes the carriage supporting the stylus, lens, lamp, prisms and screen to move with reference to the thread, which remains stationary. Upon moving the micrometer head an amount corresponding to one thread interval the stylus comes to a position in the next thread similar to the position in the preceding thread and the micrometer head is adjusted until the image of the filament coincides with the index line as before. The micrometer reading is again recorded. The difference between the two micrometer readings indicates directly the pitch interval passed over.

13 In a similar manner each thread interval may be measured and the pitch along the entire threaded portion may be investigated. The stylus, lens, lamp and screen form merely a sensitive optical indicator which serves to enable the pitch to be measured with a micrometer head. It is interesting to note that during the course of movement of the stylus from one thread to the next that it climbs up over the crest of the thread and down into the next groove. During this movement the image of the lamp filament is no longer confined to the screen, but the image is again brought back to the index point when the correct position in the next thread is obtained.

14 The optical indicating apparatus forms a convenient means of standardizing the micrometer head M. When this is done a thread gage is inserted in the machine as if it were to be tested and flat-end standards or size blocks are inserted between the micrometer spindle and ball contact against which it rests, the carriage being kept stationary and the image of the filament brought back to the

same point with the stylus in the same thread of the thread gage at each observation.

15 Questions have been asked as to the result if a thread gage is not concentric with the centers. If any such indication is present the screw can be revolved 180 deg. and again tested, or it may be turned end for end in the centers of the machine. Experiments in which this procedure was taken with a large number of thread gages indicate that the difficulties of this nature are of little importance.

16 Fig. 2 shows a recent development of the National Physical Laboratory in a pitch-measuring machine. This is similar in principle to the one just described. The main difference to be noted

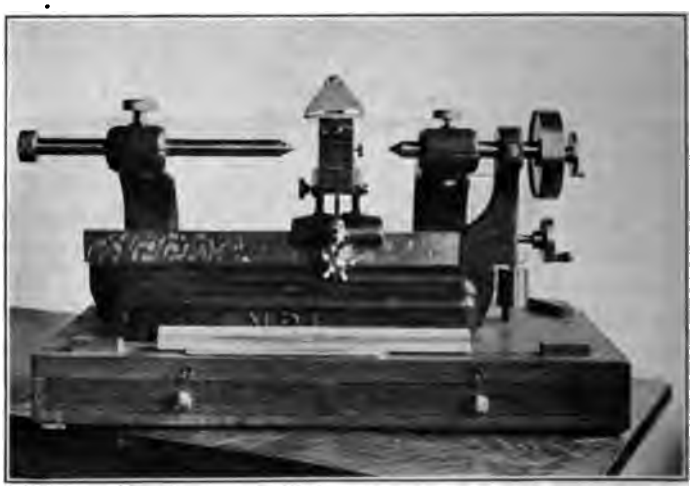


FIG. 2 PITCH-MEASURING MACHINE RECENTLY DEVELOPED BY THE NATIONAL PHYSICAL LABORATORY

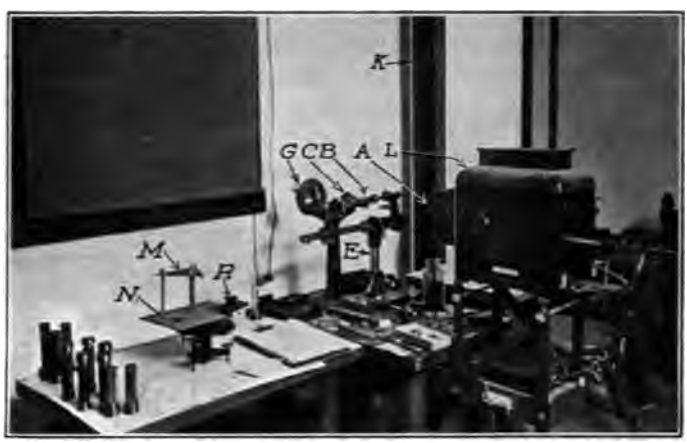
is the use of a mechanical indicator which permits the machine to be operated in strong daylight, whereas the optical indicator requires a subdued light or a shade around the ground glass. The micrometer-head arrangement in this machine permits the lead error to be read directly.

MEASUREMENT OF FORM AND ANGLE OF THREAD

17 In the measurement of thread form or thread angle various methods such as those employing microscopic devices, conical test points, and other forms of angular test pieces used in connection with visual inspection, have been investigated and tried out, but

ıctically all of these devices have been discarded in favor of the ɔjection lantern. A general idea of the arrangement used at the ıreau of Standards for the projection lantern may be obtained ɔm Fig. 3.

18 The operation of the projection lantern involves the placing the thread to be examined in a beam of parallel light and, by ɜans of a suitable lens system, the projection of the shadow of the ɜad on a distant screen. In the apparatus shown in Fig. 3, the ht from a 10-ampere arc enclosed in housing *L* is emitted through ɜ condensing lens *A* and directed toward the projecting lenses *B* d *C*. The screw is placed at the focus of the lenses *B* and *C*. The



'IG. 3 ARRANGEMENT OF PROJECTION LANTERN FOR THE MEASUREMENT OF THREAD FORM OR THREAD ANGLE

ɔjection is then directed upward by a prism *G* to a mirror (not ɔwn) which is supported about 10 ft. above the prism on the umn *K*. The projection is then directed down by the mirror to ; top of stage *N* which forms the screen and carries the standard gle *M* used in the examination of the thread form. As it is neces- y that the parallel beam of light pass through the thread at the ix angle so that the shadow cast will be a true cross-section of the ead form, the lamp housing which carries the condensing lens *A* is oted about a point beneath the lens *B*. This insures that the ım of parallel light emerging from the lens *A* will always be ected at and fill the lens *B*.

19 *Adjustments for Examination.* The setting up of a thread

gage for examination requires but a slight amount of adjustment. The stand E is provided with a motion for raising and lowering the thread, a motion for focusing the thread, and another motion for moving it along its axis in order that various portions of the thread may be brought into the center of the screen. The screw to be examined is supported by the spring centers which are carried on the stand E. For convenience in making observations it is raised until the center of the beam of light is passing the under side of the thread. The lamp L is then turned about the axis of its support until the parallel rays of light emerging from the lens A pass through the helix angle, which happens when the fringe pattern formed about the image of the screw due to imperfect focus is symmetrical. The screw is then brought into focus by a slow-motion arrangement and the required adjustments are complete.

20 *Measurement of Angle.* The examination of the thread angle is conveniently made with a device shown on the table in Fig. 3. With this arrangement the standard angle M, known to be 60 deg., is supported by three columns on the revolving stage or screen N, which rests on a graduated circle or protractor head. In the protractor shown in Fig. 3 the graduated circle was obtained from a theodolite. During the examination of the thread angle, the opaque standard angle M is adjusted so that its shadow occupies the light space of the projected image which is cast on the surface below at N. The standard angle M is revolved so that one side exactly matches with the shadow of the thread as cast below and the reading of the graduated head is obtained through a magnifying glass. The gage is then shifted parallel to its axis by means of a slow-motion device on the stand E until the image of the other side of the thread approximately coincides with the other side of the standard angle. The standard angle is then revolved by a slow-motion screw operating the graduated circle until it again lines up with the other side of the thread, whereupon a reading of the graduated circle is again obtained. The difference between the two readings shows directly the error of the included angle or thread if the standard angle M represents the correct thread angle.

21 Further application of the protractor arrangement is in the determination as to whether the thread is symmetrical about a line perpendicular to its axis. This may be verified by revolving the standard angle and matching it with the crest of the thread, or by matching a straight edge which is placed perpendicular to a bisector of the standard angle with the crest of the thread.

22 *Accuracy of the Method.* It should be specially pointed out that the "shadow protractor" is an exceedingly effective device for the measurement of thread angles, much more so than any protractor, lying directly on the plane of the shadow, could be. This is because the eye is viewing two objects of similar character, namely, two shadows. When adjusting the gage for a reading, the shadows of thread and gage are made to approach and the protractor is angularly adjusted until only a faint, even thread of light remains between the two. Under these circumstances, an inaccuracy of but a few minutes is easily detected. Furthermore, the operation of the protractor is rapid. In case of particularly defective threads, exposures of the projection may be made on any photographic developing paper — with an exposure time determined experimentally — and a permanent record obtained of the condition of the thread.

23 *Construction of Lantern.* The selection of the projection lens is important. It must be free from distortion over the portion of the projected shadow employed in making measurements. It is desirable also that a short-focus lens be employed in order that a reasonable magnification may be secured with a minimum distance between the lens and the screen.

24 A lens which satisfies these conditions very well has been secured by combining a 32-mm. aperture, 152-mm. focus, telescope objective (lens *B*), with a Tessar Series 11B, 4 × 5 photographic objective (lens *C*). These are mounted in a brass tube so that their separation can be adjusted to a point where the distortion effects are a minimum. When properly adjusted these lenses *B* and *C* have a combined focal length of approximately 100 mm., and a magnification of 50 is obtained with a screen at 5.6 m. from the lenses.

25 Another lens which has been used in place of both lenses *B* and *C*, is a Tessar Series I C, 75-mm. focus, photographic objective. This lens will give a magnification of about 70 with the same screen distance as with the combination of lenses previously mentioned.

26 For the prism, it is necessary to secure one which has its three faces accurately flat to within about one wave length of light. The same degree of flatness is required in the mirror, and in addition the mirror must be silvered on the front.

27 *Omitting the Prism and Mirror.* It will be found that prisms and mirrors of the required accuracy are expensive and, moreover, difficult to secure. However, convenience may be sacrificed and the prism and mirror omitted. The image is then thrown horizontally on to a vertical screen and the same measurements made. While

the Bureau has not developed a form of shadow protractor for vertical images, it would not be difficult to arrange the protractor for that purpose.

MEASUREMENT OF CORE DIAMETER

28 The measurement of the core diameter of thread gages is in most cases a simple matter. It is mentioned at this point because the examination of the core diameter is generally included in the operation of investigating the thread angle and thread form while the gage is in the projection lantern previously described. It is the practice in most specifications to call for thread gages cleared or cut below the nominal flat required by the regular United States form at the root of the thread. This is done to facilitate lapping. In order

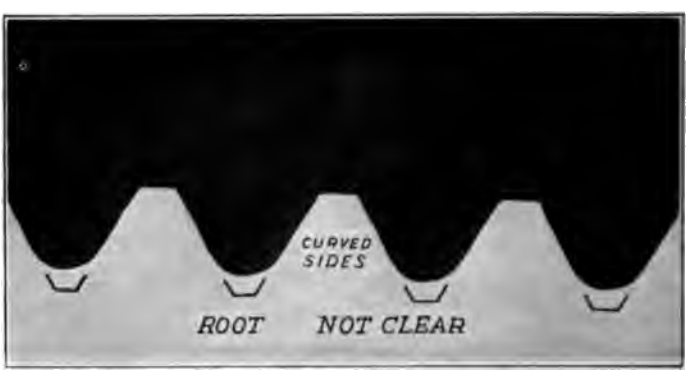


FIG. 4 PROJECTION SHADOW SHOWING THREAD NOT SUFFICIENTLY CLEARED AT THE ROOT

to determine whether or not a gage is properly cleared when examining the projected shadow, it is only necessary to insert a suitable templet corresponding to the pitch of the screw being measured. If the projected shadow of the thread shows that it is clear below the templet form, it is passed as being correct. Fig. 4 shows a thread which has not been cleared sufficiently at the root.

MEASUREMENT OF FULL DIAMETER

29 The measurement of the full diameter of plug thread gages is accomplished by the ordinary forms of flat-face micrometers or other suitable end-measuring instruments used in connection with properly authorized standards. These measurements are so simple and familiar to any one making gage inspections that no further comment will be made in this connection.

MEASUREMENT OF EFFECTIVE DIAMETER

30 Of the various methods which have been proposed for measuring effective diameters of male thread gages, the three-wire method is believed to be the most accurate and satisfactory. This method has been in common use for about fifteen years. In measuring screws by the three-wire method, cylinders accurately ground and lapped to size and diameter are used. These wires or cylinders are inserted in the thread two on one side and one on the other. A measurement is then made directly over the tops of the wires by means of an outside micrometer or other suitable measuring device. From this measurement and from the size of the wire the effective diameter of the screw can be computed.

CHOICE OF WIRES

31 In the choice of wires any size may be selected which will permit the wires to rest on the flanks of the thread and still project above the top of the thread. It is best, however, to choose wires of such a size that they touch the sides of the thread half-way down, or, in other words, at the mid-slope. In this case errors in the included angle of the thread have no effect on the measurement of an effective diameter. Moreover, the time spent in computations is greatly reduced. The best sizes of wire for various threads may be computed from the following approximate formula:

$$G = \frac{P}{2} \sec a$$

where G = diameter of wire, in.
P = pitch in in.
$a = \frac{1}{2}$ included thread angle, deg.

For 60-deg. threads this formula reduces to

$$G = 0.5774 \times P$$

COMPUTATION OF EFFECTIVE DIAMETER

32 In the computation of the effective diameters of thread gages, if the exact conditions are recognized the formula is quite complicated and the resulting computations are very laborious. The formulæ for computing effective diameters as given in most engineering handbooks involve the use of best-size wire and do not take into account the complications introduced when considering the effects of the helix angle of the thread. These formulæ, as generally given, result in securing an answer which should check with

the outside or full diameter of the screw being measured. The effective diameter is not mentioned in these formulæ and this often leads to confusion. Reference will therefore be made here to a simplified formula for 60-deg. threads which results in the direct computation of the effective diameter. This formula is as follows:

$$E = M + \frac{0.8660}{N} - 3\,G$$

where E = effective diameter
M = measurement over the wires
N = number of threads per inch
G = diameter of wires.

In the use of this formula the term $0.8660/N$ may be computed for various pitches and the computations simplified.

33 The general formula which may be used for any size of wire which will fit in the thread and which takes into account the helix angle of the thread for precision measurements, is as follows:

$$E = M + \frac{\cot a}{2N} - G\,(1 + \sqrt{\operatorname{cosec}^2 a + s^2 \cot a})$$

where a = ½ the included angle of thread
G = diameter of the wires
s = tangent of the helix angle.

34 The above formula involves squares and square root of functions and therefore is awkward for making computations, and the following formula, which is an expanded approximation but which is accurate to better than one hundred-thousandth of an inch, is more convenient:

$$E = M + \frac{\cot a}{2N} - G\,(1 + \operatorname{cosec} a + \frac{s^2}{2} \cos a \cot a)$$

This formula is a general approximation which may be used for U. S. form 60-deg. threads, Whitworth 55-deg. threads, Lowenherts 53-deg. 8-min. threads, and for other threads of a similar nature. It should be noted that the error due to the first or simple formula for 60-deg. threads in Par. 34 rarely equals 0.0001 in., and then only when the helix angle is large.

PRECAUTIONS IN MAKING THREE-WIRE MEASUREMENTS

35 It has been claimed that measurements of effective diameter made by the three-wire method result in values which are smaller than those secured by other means, such as by thread micrometers.

This contention is probably justified in some cases and may be due to insufficient care in making measurements. It is important in making measurements that as little pressure as possible be applied on the wires with the measuring micrometers. Since the wires rest in a V-thread, a given pressure exerted on the top of the wire will have a magnified effect of distorting the wire where the contact is made on the sides of the thread. This will result in the measurement over the wires being less than it should be. Furthermore, if the wire is standardized under a light pressure and then used with a larger pressure, the diameter of the wire which is substituted in the formula for computing the effective diameter will be larger than

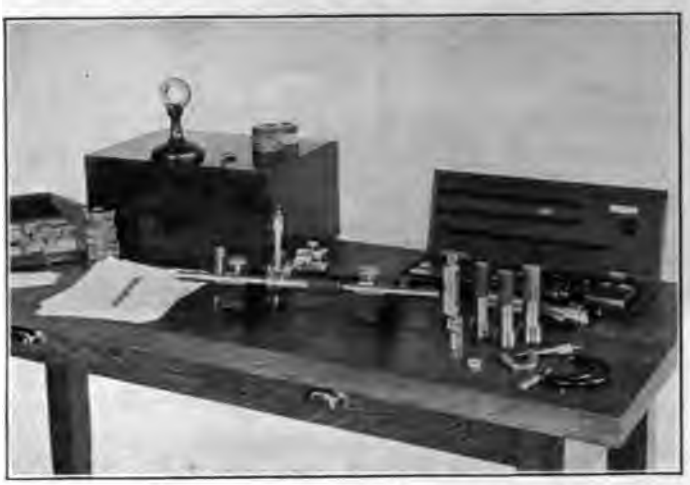


FIG. 5 BALANCED MICROMETER USED IN MEASURING GAGES BY THE THREE-WIRE METHOD

it should be. This difference is multiplied by the factor 3 in the formula and the tendency is to make the result small. Excess pressure is often placed upon the wires during the measurement by use of ratchet or friction stops on micrometers; or by an unskilled operator, and sometimes on account of the arrangement of the wires and the screw thread when the measurements are taken. It is poor practice to support the screw being measured on two wires which are in turn supported on a horizontal surface, for if the screw is of large diameter the weight of the screw causes a distortion of the wires and interferes with the measurement.

36 One of the pieces of apparatus used in measuring gages by the three-wire method is shown in Fig. 5. This apparatus is known

as a balanced micrometer. In operation the screw is supported between centers as shown, and the micrometer is supported on a counterbalanced arm which is in turn carried on a cylinder resting in a V-groove parallel to the centers. As originally designed, as shown in Fig. 5, the micrometer was constrained perpendicular to the axis of the thread being tested and two wires were used. The arm supporting the micrometer was overbalanced so that a slight upward pressure was given to the micrometer in order to hold a wire at the bottom of the thread and allow the operator to insert the top wire and make a reading with ease and rapidity. After using this constrained micrometer for some time, it was found preferable to pivot

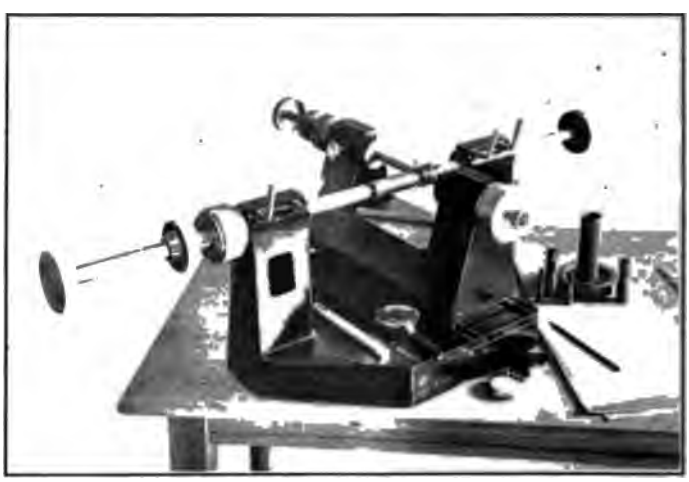


FIG. 6 APPARATUS FOR MAKING WIRE MEASUREMENTS USING TWO WIRES

the micrometer clamp on its supporting arm so as to allow a slight movement in a vertical plane passed through the axis of the screw thread and then use three wires instead of two. For this arrangement two wires are carried at the bottom and one wire inserted at the top of the thread as before. This apparatus is very simple in construction and is recommended as being very convenient where a large number of gages are to be tested

39 Another form of apparatus for making wire measurements using two wires is shown in Fig. 6. This instrument was specially designed and constructed for the Bureau of Standards. It embodies a precision bench micrometer accurate to within about two one-hundred thousandths of an inch, supported on a heavy base and

carried by steel balls. This support permits the micrometer uniform contact on the wires at either side of the thread. This machine has been found useful for threads of relatively large diameter. The instrument is of massive construction, and its rigidity, which is not common to ordinary measuring instruments, permits, when precautions are taken to avoid temperature changes, measurements which are accurate to within two or three one-hundred thousandths of an inch.

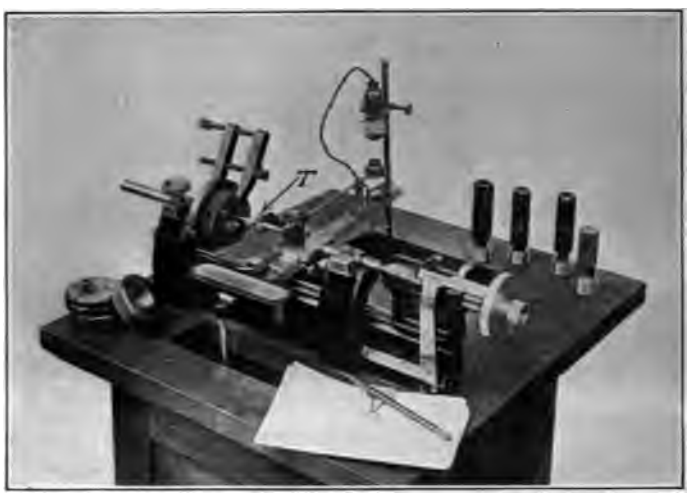


FIG. 7 APPARATUS FOR MEASURING THE PITCH OR LEAD OF A RING THREAD GAGE

TEST OF RING THREAD GAGES

38 The measurement of ring thread gages presents many problems owing to the difficulties with which observations may be made on the various elements. While there are various ways and means of obtaining the measurements required, it is not possible in most cases to work to the degree of accuracy that is obtainable in measuring plug thread gages. Very often the special apparatus required for such measurements is not available in commercial shops and it then becomes necessary to judge the perfection of the ring thread by the way which it fits on a male check or checks. The various operations required for measurement are quite similar to those given for plug gages. The procedure generally embodies the following operations:

a Measurement of pitch or lead
b Measurement of angle and form of thread
c Measurement of full diameter
d Measurement of core diameter
e Measurement of effective diameter.

MEASUREMENT OF PITCH OR LEAD

39 The measurement of pitch or lead of a ring thread gage is accomplished as shown in Fig. 7. The same apparatus is employed for measuring ring threads as for measuring plug threads, with the

FIG. 8 CASTS OF THREAD AND APPARATUS USED IN MAKING THEM

exception that an extension stylus or attachment is provided to project into the ring and transfer the motion of the auxiliary stylus to the ball stylus used on the plug thread. This auxiliary device is shown at *T*, Fig. 7. Instead of being supported on centers as is the case when a plug is tested, the ring is clamped on a faceplate and the operation then is exactly the same as previously explained for measuring the lead of the plug thread.

MEASUREMENT OF ANGLE AND THREAD FORM

40 The measurement of angle and thread form of ring threads is accomplished with the projection lantern in a similar manner to

that employed in measuring angle and thread form of plug threads. In this instance, however, it is necessary to obtain first a cast of the thread to enable the projection to be made. The casts usually used are made of a composition of sulphur and graphite containing about 7 per cent by weight of graphite. The graphite is added to eliminate reflections which would be encountered on the surface of a plain sulphur cast in the process of projection. Then, in addition, the graphite has a tendency to reduce the shrinkage of the sulphur upon cooling. The procedure in making the cast is to clamp the ring in a vise, the jaws of which have been ground smooth, and

FIG. 9 THREE-BALL METHOD OF MEASURING THE EFFECTIVE DIAMETER OF A RING THREAD GAGE

pour melted sulphur into the ring, obtaining a cast which is a segment of a circle. The outfit required for this purpose and illustrations of the cast secured are shown in Fig. 8. The operation of pouring the casts with this method is very rapid. After the casts are poured they are immediately marked with a steel stylus with a number corresponding to the test number on the gage. The measurement of the angle is made as soon after making the cast as possible, inasmuch as experiment shows that the cast warps but slightly during the first five or six hours, but that the warping is considerably greater at the end of 24 hours.

MEASUREMENT OF FULL DIAMETER

41 The measurement of full diameter is usually made part of the projection operation, as was the case of the measurement of the core diameter of plug gages. Here again it is only necessary to insert a templet in the thread shadow to ascertain whether or not the thread has been properly cleared.

MEASUREMENT OF CORE DIAMETER

42 The measurement of core diameter is usually made with an inside micrometer, Johansson inside set-up, or by the use of go and not-go plain check plugs for this diameter. This measurement of a plain inside diameter requires no further explanation.

MEASUREMENT OF EFFECTIVE DIAMETER

43 The method which is usually employed for measuring the effective diameter of a ring gage is by judging the fit of the gage on a plug thread check. This plug check is ordinarily ground off at the crest of the thread in order to make sure that the plug touches on the sides of the thread instead of at the crest. It is usually considered that when the ring fits snugly on the plug that the effective diameter of the ring is the same as the plug. This assumption, however, is not strictly true, inasmuch as there always is certain variation between the lead or pitch of the plug and the lead or pitch of the ring, and furthermore, variations of angle between the plug and the ring are always present. Both of these variations necessitate the ring's having an effective diameter larger than the plug upon which it fits snugly. In most cases the amount actually required for fit, due to differences in pitch and angle, is appreciable, sometimes as much as several thousandths of an inch.

44 In order to ascertain the effective diameter where check thread plugs are not available, the three-ball method of measurement has been adopted. In making these measurements the ring is laid on a flat surface with the axis of the thread perpendicular. Two balls are then placed in adjacent threads and a third ball is placed diametrically opposite. The distance between these balls is then taken by inserting size blocks together with a taper parallel, as shown in Fig. 9. The effective diameter can then be computed in a manner similar to that explained for male screw threads, as it is necessary to change only the signs of the different quantities of the

formula as previously given for wire measurements. The formula as corrected by the change of signs is then as follows:

$$E = M - 0.8660 \times p + 3G$$

where E = effective diameter
M = measurement between balls
p = pitch in inches
G = diameter of balls.

This formula applies in cases where the balls used touch nearly at the mid-slope of the thread.

DISCUSSION

H. J. Bingham Powell[1] (written). The number of gages inspected during the last few months by the U. S. Bureau of Aircraft Production and of the British War Mission is from 15,000 to 18,000 a month, and a program of a thousand gages a day was under consideration when the war terminated. Over 80 per cent of the gages were screw gages, with the low tolerances of two ten-thousandths of an inch on the pitch diameter and the same figure for the maximum lead error. The other gages were the complex form, flat and angle gages used in aircraft engines and aeroplane inspection generally. We employ girls for the work as far as possible, men only being needed for the more complex gages and where experience in gage making was necessary, such as in the visual inspection, etc. The girls have given most admirable service and have been found to be fully qualified by their patience, steady work and light touch for dealing with the very delicate instruments we use. Our instruments have been especially designed, bearing in mind the unskilled workers who had to use them, and are practically "automatic" in action.

For instance, our lead-measuring machine shows the correct reading to within two one-hundred thousandths of an inch by the swing of a galvanometer needle. Ten machines deal with 500 gages a day, with errors in readings almost unknown. The National Physical Laboratory pitch-diameter machine described by Mr. Van Keuren has been modified by us by fixing an attachment to it which puts a constant load on the wires and does away with the feel of the

[1] Officer in Charge of the Joint Gage Laboratories of the U. S. Bureau of Aircraft Production and of the British War Mission.

micrometer, a small lamp extinguishing when the reading is correct. The results given by the different pitch-diameter machines are thus obtained under identical conditions of loading of the wires and pressure on the micrometer spindle: the latter having on its barrel a divided wheel by which readings can be taken to a fraction of a ten-thousandth of an inch.

The horizontal type of the National Physical Laboratory optical projection lantern is used with a lens that gives a correct field 8 ft. in diameter. We photograph all the plug gages and the casts of ring gages by means of a special apparatus which takes less than one minute to operate. The photographs are measured for angle of thread and checked for form by placing them over suitably engraved glass screens illuminated from underneath.

To take casts of ring gages we have a special appliance that does the work in a few seconds. All this apparatus has been designed for dealing with our large number of gages with expediency and accuracy without having to employ highly skilled mechanics who in war time can be better employed elsewhere.

C. P. Colburn[1] (written). The object of this discussion is to show how methods of precise measurement may be simplified and adapted to practical use.

The usual trigonometric formulæ for determining the correct wire size and the over-wire dimension for determining pitch diameter of thread gages and taps is a problem too deep in mathematics for many shop mechanics. The formulæ here given are intended for the workman who is not a mathematician, but who finds it necessary to make calculations due to the fact that drawings are not generally arranged to show over-wire measurements and the correct size of wire which should be used to obtain the best results.

Measurement of Pitch Diameter of 60-deg. Thread by 3-wire System. The following formulæ will render equally correct results and may be used for all styles of 60-deg. threads by any one who has a knowledge of ordinary arithmetic. In both instances the size of wire used should be such that the points of tangency will lie in the pitch line.

The diameter of wire which will touch the sides of the thread at the pitch line is equal to two-thirds the depth of a sharp V thread (see Fig. 10). The depth is determined by dividing half the decimal pitch by the tangent of half the included angle, or by 0.57735.

[1] Major, Ordnance Dept., U. S. A.; Gage Dept., Frankford Arsenal.

$$W = \frac{2}{3}D = \frac{P\ (\text{decimal})}{1.7321}D = \frac{H}{\tan 30^\circ}$$

where

P = pitch
W = diameter of wire
H = one-half the pitch = $0.5P$
D = depth of sharp V

The pitch diameter of a thread gage or a tap may be computed by substituting the measurement over the wires and the mean diameter of wire in the formula

$$D_p = X - 1.5\,W$$

where

D_p = pitch diameter
X = measurement over wires
W = mean diameter of wires.

The dimension over the wires may also be found by adding 1.5 times the mean diameter of the wires (determined by the formula and Fig. 10) to the pitch diameter as given in Fig. 10. Any variations from the measurements thus found indicate over or under size at pitch diameter.

Test for Angle of 60-deg. Thread by Use of Wires. The angle of a 60-deg. thread may be tested by using two wires, the diameter of the larger being equal to the single depth of a sharp V thread and the smaller equal to one-third the single depth of the sharp thread. (See Fig. 11) Knowing the diameter of the wire, which is tangent to the sides of the thread at the pitch line, the diameter of the large wire can be found by multiplying that value by 3 and dividing by 2. The diameter of the small wire is equal to one-third the diameter of the large wire.

When both wires are placed in and touching the sides of the thread, they will be tangent to each other at the pitch line.

To make this system practical for the checking of angles, the small wire ($D/3$) should be made in two sizes and used as a "go" and "no go" gage. The sizes of "go" and "no go" wires are determined by the allowable tolerance of the angle. The large wire being held against the angle of the thread will permit the small "go" wire to pass underneath. The "no go" wire should not pass, if the angle is within the specified tolerance.

The larger wire touches slightly below the top of the U. S. Standard thread approximately a distance equaling the flat on the top of

thread. The small wire lies on the angle at the same distance from the root of the thread. This makes the approximate range of the angle test about three-quarters the depth of the thread.

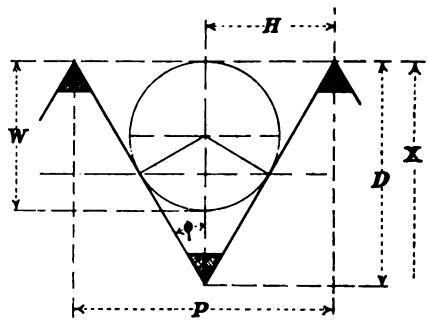


FIG. 10 DIAMETER OF WIRE TO TOUCH THREADS AT PITCH LINE

The writer recommends that working drawings show methods of inspection and all necessary dimensions. This should obviate many errors, usually resulting in the complete loss of the article,

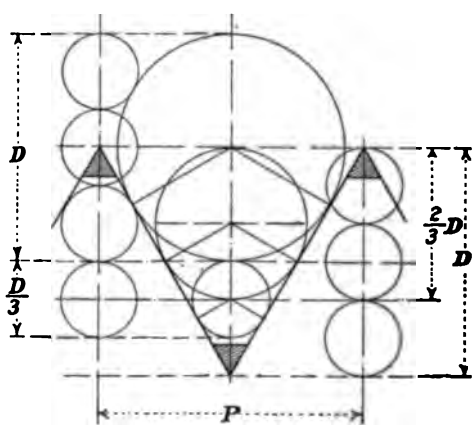


FIG. 11 CHECKING ANGLE ON 60-DEG. THREADS WITH STANDARD BEST WIRES

and also reduce the cost of computation, which would be made only once, whereas in the present practice the shop mechanic and inspector usually work separately, thus naturally increasing the cost of the product.

LUTHER D. BURLINGAME referred to the joint meeting of the Society with the Institution of Mechanical Engineers in England in 1910, when Sir Richard Glazebrook was kind enough to say that, while Great Britain had shown the way toward standardization and toward interchangeability of parts, it had been the part of America to put them into practice. Now the table was turned, and as we read of what had been accomplished by the Bureau of Standards, we found that we had ourselves been learning from the advanced work which had been done in Great Britain so that the two great Anglo-Saxon peoples were working together, each to help the other in carrying these matters toward solution. It was to be remembered, however, that the final question was not that of gages, but of insuring that the final product would be workable and satisfactory as to fit.

Mr. Wells had expressed the thought that there were so many steps in the question of tolerances, that a much more complicated problem was presented than would seem on the face of it. As an aid to offsetting this, however, we had the possibility of combining the errors of lead and diameter in such a way that an increased error of diameter might be compensated for by an error in lead, and as far as we could take advantage of this condition we could increase our tolerances; but the last word would not be said in this matter until we had means of combining measurements so that we knew what was the combined error of diameter and lead.

H. H. SUPLEE recalled the fact that the Bureau of Standards was established as a result of a paper presented before the Society in 1889 by James W. See, of Hamilton, Ohio. Mr. See wrote a paper on standards, and after he had presented it, he recommended that there should be a Bureau of Standards established by the Government. A committee of the Society went to Washington and the Bureau of Standards was established. The National Physical Laboratory was started after that, but the whole idea of the Bureau of Standards originated in the Society.

FRANK O. HOAGLAND said that in the matter of pipe-thread gages extreme accuracy was not required, since an additional quarter turn of the pipe would give a tight joint, due to the taper used. This fact should be borne in mind when making gages to specific tolerances.

No. 1668

STANDARDS FOR LARGE TAPER SHANKS AND SOCKETS

By Luther D. Burlingame, Providence, R. I.
Member of the Society

War needs have demanded the construction of machine tools embodying taper shanks and sockets of larger dimensions than it has been customary to use. Most of the tapers established in the early days present irregular variations in size and in depth, even within the same system, and the application to the large sizes of the rules followed in proportioning these early types does not give the dimensions required to meet the new conditions. To supply this deficiency, the Brown & Sharpe Mfg. Co., after a careful study of the present established tapers and of the experience of several prominent manufacturers, has developed the set of "Magnum" standard tapers described at length in the paper.

In these tapers the diameters at the large end vary from 4 to 14 in. and those at the small end from 3¼ to 12 in. The depth of taper is made equal to twice the diameter of the large end plus 4 in. The selected standard taper is ¼ in. per ft.

ONE of the many problems presented by war needs is that of designing machine tools of far greater size than any previously built, and, in proportioning those which require the use of taper shanks and sockets, the taper per foot and the length must be determined.

2 No standards are known to have been established for tapers of the large sizes now required for these machines or which the exigencies of the near future may require. The problem of working out such a standard was presented to the Brown & Sharpe Mfg. Co., and after an extended investigation and study of the conditions to be met, it has arrived at the tentative form described in this paper. The choice was based on a study and analysis of present established tapers, an investigation of the laws governing the use of tapers and a referendum of experience and opinion from a number of manufacturers and engineers who, because of their close contact with conditions most nearly like those desired to be met, it was felt would best be able to judge of the requirements.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

HISTORY

3 Up to within comparatively recent times, tapers for shanks and sockets above 3 in. in diameter have had a somewhat limited use. For lathes, drill presses, boring mills, and milling machines, where the conditions of use are somewhat similar, the tapers used have varied from ½ in. to 1½ in. per ft., with widely varying lengths. Table 1 gives particulars of those most widely used and generally described in textbooks.

4 This wide variation in practice, where the conditions seem about the same, raises a question as to what, if any, are the reasons for such variation, and as to whether any rules can be laid down determining the most satisfactory taper per foot to be used. it would not be feasible to change tapers now in extensive use, t

TABLE 1 DATA ON TAPERS IN GENERAL USE

Taper per ft., in.	Included angle	Ratio	Name	About when introduced	Where Used
½	2° 23′	1 : 24	Brown & Sharpe	1860	Milling machines and general
9/16	2° 52′	1 : 20	Jarno	1889	Reed lathes, Pratt & Whitney chines, etc.[1]
5/8	3° 59′	1 : 19½	Morse	1862	Twist drills, drill presses, etc.
¾	3° 35′	1 : 16	Sellers	1862	Lathes, boring machines, machines, etc.
1	4° 46′	1 : 11	Cambria	.....	Steam-hammer piston-rod ends
1½	7° 9′	1 : 8	Muir (England)	.....	Milling machines, "patent lings" for arbors

[1] Also since used for German metric tapers.

would be a mere academic question were it not for the fact, alre pointed out, that new taper sizes are required.

5 Most of the tapers mentioned in Table 1 were establishe the early days, before the question of standardization was gi much attention, and so the variations in size and depth are irreg even in a given system. Such formulæ as exist, if followed for proposed larger sizes, would not give the proportions require meet the new conditions. Thus the Brown & Sharpe taper, increasing somewhat uniformly in depth to No. 12 (1½ in. in eter at the small end), would be longer than usually neces the same proportions were carried above that size. For this when B. & S. sizes above No. 12 were established at a lat than the small sizes, a new ratio for length was used, by whi sizes to No. 18 (3 in. in diameter at the small end) do not

s rapidly in depth relative to the diameter as is the case with the naller sizes.

6 The "Jarno" taper, proposed by Oscar J. Beale of the Brown : Sharpe Mfg. Co. (and given its name because of the pen name Jarno" under which Mr. Beale wrote), has an established ratio of iameter to length each $\frac{1}{8}$ in. of diameter at the large end and each $\frac{1}{5}$ in. at the small end adding $\frac{1}{2}$ in. to the length. This standard, ecause of the easily remembered relations of its dimensions, has ppealed to designers and has already come into quite extensive se. When the formula is applied, however, to large sizes, such as e here considered, it does not give practical proportions. So far s other standards now in use follow well-defined proportions in ie relation of length to diameter, these proportions also fail when pplied to large sizes.

TAPER PER FOOT

7 As shown in Table 1, the well-established tapers for shanks id sockets now in use vary from $\frac{1}{2}$ in. to 1 in. or more per ft., the ndency being to use a somewhat steeper taper for the larger than r the small sizes, perhaps because with small tapers, the liability slip produced by the work is not so great and the "bite" of the iper when forced into the socket is sufficient to secure effective iving. In the larger sizes, tenons or tongues must be provided to d in driving, and in the still larger sizes keys of some form are eeded as, unless the angle of taper is very slight, the tenons are ible to be twisted off. When such auxiliary means of driving is ovided the taper can be made steeper, giving the advantage that ie parts can be more easily separated.

8 Tapers as slight as $\frac{1}{2}$ in. per ft. have given satisfactory sults in milling machines and other machine tools, where they ive been in constant use for at least the last sixty years. The bite" on the small sizes is sufficient, when driven in place, to old without working loose under jar, while the angle is not so nall as to prevent driving apart when desired. It is found, how- er, that occasionally a taper of $\frac{1}{2}$ in. per ft. will stick so tightly to require considerable force to separate the parts, perhaps in ch cases as where a cold arbor is driven into a heated spindle. ith a taper as slight as $\frac{1}{2}$ in. per ft. there is seldom trouble from iving the tenon twist off, as is so often the case with twist drills ade with a taper of approximately $\frac{5}{8}$ in. per ft., and where on ac- unt of the greater taper the "bite" of the taper fit does not carry great a proportion of the load.

PRINCIPLES ON WHICH TAPERS DEPEND

9 At the time Mr. Beale proposed the Jarno taper, he made an investigation of the principles on which the taper of shanks and sockets should be proportioned, and published his findings in the *American Machinist* of October 31, 1889, p. 3. His analysis is a clear statement of conditions governing the taper per foot and concluded that:

> If a center be of a taper whose sides make an angle of less than 4 deg., it is not likely to slip out, after being driven in, even though it be oiled. An angle of 4 deg. makes a taper of nearly $\frac{1}{8}$ in. per ft. No center, so far as I have seen, has a taper greater than this, which is interesting as indicating that the machinist, in practice, has not exceeded the angle of safety given in the textbooks. . . . The smallest center angle that I know is something less than $2\frac{1}{2}$ deg., which in practice has been found to be small enough. We are, therefore, at liberty to choose any angle of taper between 2 and 4 deg.

10 Mr. Beale chose for the Jarno taper, 0.6 in. taper per ft. (2 deg. 52 min.) as an average between these limits. This gives a ratio of 1 in 20, a ratio which has since been adopted for the German metric standard and is especially adapted for use with a decimal system of measurement. In applying it to the English system of measurement, however, it gives the dimension at one end of the taper in tenths and at the other end in eighths, a feature which, while not especially objectionable, lacks the advantage derived from using the taper of $\frac{3}{4}$ in. per ft., which gives, with each inch of depth, $\frac{1}{16}$ in. variation in diameter, so that when applied to large tapers, whose depth may be made to vary by 2 in. or 4 in., the diameters at both large and small ends come in whole or convenient fractional sizes.

11 A taper of $\frac{3}{4}$ in. per ft. also gives an advantage over 0.6 in. or other tapers with a less steep taper in the ease with which it will release when it is desired to drive it out. Further, it is a taper which apparently is now in most general use for large work, although its proportions, as far as the writer knows, have not previously been standardized.

12 If the "bite" of the shank is to be depended on to a considerable extent to do the driving, the taper should be small, even at the risk of finding occasional difficulty in separating the parts. On the other hand, if adequate means of driving is to be provided in addition to the "bite" of the taper, there are advantages in making the taper greater, although not so great as to allow jarring loose or dropping out readily.

13 Assuming that in all cases of machine tools using these la

either longitudinal keys or cross-hold-back keys or both used for driving, a greater taper per foot can be used, thus ng the advantage of easy removal with no sacrifice in driving ey.[1] To meet these conditions. a taper of $\frac{3}{4}$ in. per ft. for zes seems ideal, based on scientific grounds and also on the nce of users.

LENGTHS FOR TAPERS

While the length can be more elastic, a variation being less onable than in the case of the diameter or taper per foot, it is le to standardize it also. As previously pointed out, the already established do not give proportions for lengths suited sizes. Thus the Jarno formula would make a taper of 14 in.

MAGNUM STANDARD TAPERS, DESIGNED BY THE BROWN & SHARPE MFG. CO.

Diam. at large end, in.	Diam. at small end, in.	Depth of taper, in.	Remarks
4	3¼	12	
5	4⅛	14	
6	5	16	Taper = ¾ in. per ft.
7	5⅞	18	Depth of taper = 2 × diameter at large end + 4 in.
8	6¾	20	
10	8½	24	
12	10¼	28	
14	12	32	

eter at the large end, 56 in. long — much too long for practical nd adding an excessive amount to the cost of both gages and s as well as of the machine.

THE PROPOSED STANDARD

By the use of a constant, a formula has been derived appli- ver a wide range, and giving, it is believed, satisfactory ions. Fig. 1 illustrates the relation of the proposed taper d for length as derived from this formula, to the established & Sharpe sizes, showing that these new tapers follow in a progression beyond the largest established Brown & Sharpe

r methods of applying these keys see *American Machinist*, vol. 44, no. 26, where L. P. Alford describes and illustrates the system of keying pro- Carl G. Barth.

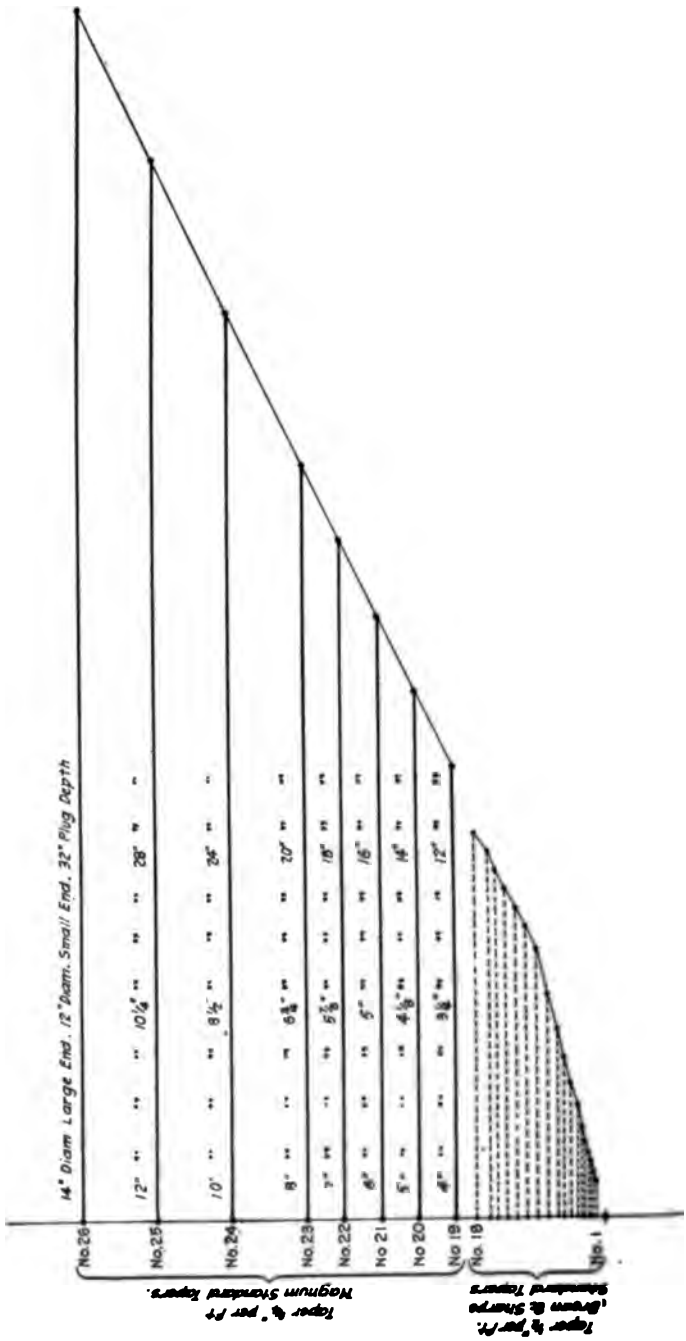


FIG. 1 RELATION OF PROPOSED STANDARD TAPER LENGTHS TO ESTABLISHED BROWN & SHARPE SIZES

16 As a result of this investigation the sizes in Table 2 are proposed, to be known as Magnum Standard Tapers.

17 The reason for beginning the numbering at 19 is to avoid lapping on to the numbers of any of the systems now in use, No. 18 of the B. & S. standard being, so far as known, the largest standard

TABLE 3 EXPERIENCE OF MANUFACTURERS WITH LARGE TAPERS

Name.	Kind of machines.	Taper per foot recommended	Depth recommended	Remarks
William Sellers & Co. Inc. Coleman Sellers, Jr.	Lathes; horizontal boring machines	¾ in.	3 × diam. at large end (or a little less)	Have used up to 8 in. diam.
Mesta Mach. Co. J. E. Mesta, Asst. Supt.	Rolling-mill machinery, etc.	½ in.	3 × diam.	.....
Newton Mach. Tool Works Nicholas P. Lloyd, Gen. Mgr.	Milling machines, etc.	Use ⅝ as std.; rec. 1 in. for large	.....	Have used to 6 in. diam.
Labor Mfg. Co. Wilfred Lewis, Pres.	General	0.6 or ¾ in.	.....	.....
Mead-Morrison Mfg. Co. J. T. MacMurray and Robt. Gow	General	1 in.	About 1½ in. × diam. + 2 in.	.....
Westinghouse Elec. & Mfg. Co. E. R. Norris	General	¾ in.	3 × diam.	
Clement & Miles W. J. Hagman	Steam hammers	½ and ¾ in.	.....	The greater taper used for sizes above 3½ in.
	Steam forge hammers	1 in.	.....	Sizes 2¼ to 12 in. diam.
	Lathes	¾ and 1 in.	Up to 5 in. at large end, 2½-3×diam. 5 in. & over, 2.1 & 2½ × diam.	Sizes above 5 in. are 1 in. taper per ft.
	Drilling & boring machines	⅝ in.	.....	All sizes
	Milling machines	¾ in.	.....	All sizes

is yet suggested. No. 19 of the new system is proportionately larger than the B. & S. No. 18.

18 It will be noted that the diameters at the large end are made basic and vary by inches, and with the length of taper obtained by the formula the diameters at the small end are in convenient fractional sizes.

EXPERIENCE OF MANUFACTURERS

19 Before determining on the proportions of the Magnum tapers the question of the proportions of large standard tapers was taken up with manufacturers and engineers having experience along these lines, in some cases by personal conferences, in others by letter. Table 3 gives a digest of the opinions received from various sources in answer to the writer's inquiry as to their past experience with large tapers. As, however, these opinions cannot be made sufficiently clear in such a condensed chart, the views of those consulted are given more in detail in the Appendix.

APPENDIX

EXPERIENCE AND OPINIONS OF USES OF LARGE TAPERS

20 *William Sellers & Co., Inc., Philadelphia, Pa.* — *Coleman Sellers, Jr.* — Some years ago, after various experiments and experiences with tapers varying from ½ to 1 in. per ft., this company adopted ¾ in. taper per ft. as the standard for all their work. This has been used up to tapers of 8 in. diameter at the large end, the larger sizes being used for gun lathes and boring machines, and no trouble has been experienced from its use.

21 This company feel that a taper as great as ¾ in. per ft. requires some positive means for holding it from working loose, in the case of horizontal boring mills where the operation of back facing means in addition to the vibration, a direct pressure tending to draw the arbor out. It is also their common practice to use a holding-in-key fitting crosswise through the socket and shank, and having a taper of 5 deg.

22 Their practice is to make the length of fit about three times the diameter at the large end. They consider this rather extreme in length and feel that a somewhat shorter length would answer just as well, and perhaps be even better. They believe that a steeper taper, even to 1½ in. per ft. might be used, but it would not be as satisfactory as the ¾-in. taper per ft. which has been in successful use by them for so long a time. As to the smaller degree of taper, say ½ in. per ft., they would not expect any greater difficulty for large diameters in proportion to the size than is experienced in using this taper for the smaller sizes.

23 *Mesta Machine Co., Pittsburgh, Pa.* — *J. E. Mesta, Asst. Gen. Supt.* — For tapers above 3 in. size this company uses ½ in. taper per ft., and obtains very good results. This seems in their opinion about the best to use. They say it will not bind tightly enough to make it difficult to remove, and it will not jar loose. As to the depth of taper fit, they make it three times the diameter with good results.

24 *Newton Machine Tool Works, Inc., Philadelphia, Pa.* — *Nicholas P. Lloyd, Gen. Mgr.* — This company uses the Morse taper, approximately ⅝ in. per ft., for all of their sizes, although they have not used taper sizes much over 6 in. in diameter. They have made special tapers to order for customers all the way from ½ in. to 1 in. taper per ft., and as far as reported, such tapers have given satisfactory results. The view was expressed that the larger sizes should be of

a steeper taper than the small sizes, 1 in. taper per ft. being suggested for the largest sizes.

25 *Tabor Mfg. Co., Philadelphia, Pa. — Wilfred Lewis, Pres.* — While not engaged at the present time in work requiring the use of large tapers, Mr. Lewis has had in the past much experience in the use of tapers, and expressed himself as favoring $\frac{3}{4}$ in. taper per ft., as a general standard for sockets and shanks, which he regrets has not been generally adopted, so as now to be a universal standard, giving, in his opinion, satisfactory results for either large or small sizes. He believes there is no reason why a large-diameter taper should have any greater angle (taper per foot) than a small diameter. He admires the convenient basis of the Jarno taper, and believes this would have certain advantages if generally adopted. He does not have any great choice between 0.6 or $\frac{3}{4}$ in. per ft., but believes that one of these should become the standard.

26 *Mead-Morrison Mfg. Co., East Boston, Mass. — J. T. MacMurray, Works Mgr., and Robert Gow, in Charge of Tool Dept.* — Mr. Gow, reporting through Mr. MacMurray, with whom he was associated for many years at the Pond Plant, Plainfield, N. J., says, in reference to standard arbor tapers, that according to his experience it is necessary, when increasing the diameter of a taper, also its length, that the taper per foot should be increased. He states that oftentimes a taper of $\frac{1}{2}$ in. per ft. will wedge under certain conditions so that it is almost impossible to remove it, and that on the larger sizes this difficulty would be increased. He considers that a practical working taper for the largest sizes should be 1 in. taper per ft.

27 *Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. — F. S. Walters, in charge of Small-Tool Dept.* — Mr. Walters suggests $\frac{3}{4}$ in. taper per ft. as a standard for large sizes, and not less than three times the diameter for length. He explains that it is intended to use with this a draw key or a draw bolt. On boring bars and arbors we always provide for a draw key and on this account more taper may be allowed and the bars will come out more readily. If a lathe center is made with $\frac{5}{8}$ in. or less taper per ft. it is somewhat of a task to get the centers out. Therefore, since they cannot work loose on account of being keyed, I would suggest $\frac{3}{4}$ in., which will allow them to come out more readily."

28 *Bement-Miles Works of the Miles-Bement-Pond Co., Philadelphia, Pa. — W. J. Hagman, Gen. Mgr.* — After referring to the standards used for tapers on steam trip hammers, forge hammers, etc., Mr. Hagman says that on lathes, centers up to 5 in. diameter at the large end are made with $\frac{3}{4}$ in. taper per ft. and vary in length from 3 diameters on the larger sizes to $2\frac{1}{2}$ diameters on the smaller sizes. Centers larger than 5 in. are 1 in. taper per ft., the lengths being from 2.1 to $2\frac{1}{2}$ diameters.

29 On drilling and boring machines the tapers are Morse standard within the Morse range, and for larger sizes they use reamers of their own make, adhering to the $\frac{5}{8}$-in. taper per ft. There are some very old machines of these types infrequently built and which have tapers $\frac{3}{4}$ in. per ft. Mr. Hagman considers that either $\frac{3}{4}$-in. taper per ft. or $\frac{5}{8}$-in. taper would be satisfactory.

30 For milling machines, they use $\frac{3}{4}$-in. taper per ft., for all sizes, the lengths varying from 3 diameters on $2\frac{1}{2}$-in. diameter hole, to 2 diameters on 5-in. diameter hole. It is thought important not to make the tapers on milling machines very coarse, as the vibration of these machines when in operation, has a tendency to loosen the taper sockets.

DISCUSSION

WILFRED LEWIS (written). I think that Mr. Burlingame has done well to advise the adoption of the ¾-in.-per-foot taper for large taper shanks and sockets, but am not so sure about the lengths recommended, and do not see why all shanks and sockets should not be similar in every respect. I am disposed to agree with Mr. Walters of the Westinghouse Company in advising a length of three times the diameter, and if this is long enough for large shanks and sockets, I believe it is long enough for anything, large or small.

Mr. Burlingame has also done well in his choice of sizes: 4, 5, 6, 7, and their multiples by two, making 8, 10, 12, 14; thus forming the basis for a rational progression in sizes, stepping up again to 16, 20, 24, 28, or down by division to 2, 2.5, 3, 3.5 and so on, as far as may be desired. I do not believe, however, in designating these by the numbers 19, 20, 21, etc., as proposed. No. 19, also, conflicts with No. 19 of the Jarno taper. I would prefer to designate the tapers by the sizes themselves. A 4-in. shank or socket, for instance, is self-explanatory, while No. 19 calls for interpretation.

There was a movement years ago to abolish all numbered sizes for any purpose whatever, and I think it should be revived. The late James Christie was active in the promulgation of this idea, which I found quite easy to follow, because the actual size was always the thing desired, while the arbitrary number given to it was a matter of no interest whatever.

I suggest, therefore, as an amendment to the system proposed that the number of the taper be omitted, and that the length of taper be made three times the diameter at large end, instead of twice plus 4 in.

WILLIAM BACON (written). During the past three years the Reed-Prentice Company has made a study of the subject of lathe centers and has adopted a formula based on the Jarno taper.

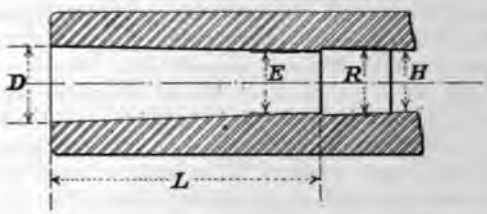
The taper adopted is 0.6 in. per ft.; length = 2 × diameter of large end + 1¾ in., and the number of the taper is designated by diameter in inches × 8. Table 4 gives the dimensions for the lathes made by this company.

Practical experience has shown that a taper approximately ¾ in., or as in the Jarno taper 0.6 in., per ft., gives excellent results on both the hold and ease of drifting center from socket. My preference

would be for this taper, since it meets all requirements so well and is so widely recognized, either as a 0.6-in. taper, or an approximation to it, as in the B. & S. and Morse tapers, etc.

If a new standard is to be adopted, to be known as the "Magnum" standard taper, why not give it its own numbers without regard to any other system? If the Jarno formula, modified, were adopted, the regular Jarno series numbers could be used without conflict and I might suggest that they be designated as the "Magnum-Jarno" standard taper.

TABLE 4 DIMENSIONS OF LATHE-SPINDLE TAPERS EMPLOYED BY THE REED-PRENTICE COMPANY



Reed-Prentice Co. Modified Jarno Taper: No. of taper = D (in inches) × 8; $L = 2D + 1.75$ in.; $E = D - 0.05L$; $R = E + 1/32$ in.

Size of lathe, in.	12	14	16	18	20	24	27
Taper No.	11	12	13	15	17	19	23
D (in inches) =	1⅜	1½	1⅝	1⅞	2⅛	2⅜	2⅞
E (in inches) =	1.150	1.263	1.375	1.600	1.825	2.050	2.500
L (in inches) =	4½	4¾	5	5½	6	6½	7½

THE AUTHOR. A length of three times the diameter, as suggested by Mr. Lewis, would be far from applicable to the small sizes, a constant being needed to make the formula cover a wide range. As to the use of designating numbers, the tendency in commercial matters is to have a number which can represent a variety of measures, so that the number can be used, without long description or explanations, either by correspondence, telegram, or whatever method of communication may be used. We find in our catalogs it is often desirable to have a number to represent a given article, and in that way the number tells the whole story. In designating tapers a number has the advantage of specifying length, diameter and taper per foot, the three important features, and is simpler than an explanation including these varying elements.

No. 1669

THE BRITISH ENGINEERING STANDARDS ASSOCIATION

By C. le Maistre,[1] London, England.
Non-Member

To secure interchangeability of parts, to cheapen manufacture by the elimination of waste and material and to expedite delivery are the primary objects of standardization. The British Engineering Standards Association includes over 900 members and deals under one central authority with standards relating to practically the whole field of engineering. As part of the work accomplished by the Association the author mentions the standardization of steel-section materials, tramway rails, special steels used in the automobile industry, screw-thread tolerances, rules for electrical machinery, designs for locomotives, specifications for portland cement, road material, aircraft material and parts. The most recent activity has been the standardization of details in the construction of ships and their machinery. Much of this work has been undertaken at Government request as war measures.

The funds for the work have been provided by the Government and industries concerned. The sole executive authority of the Association is vested in the Main Committee, consisting of members nominated by the leading technical institutions.

A considerable amount of work of an international character has been undertaken and local committees of engineers and traders are being set up in the more important trading centers of the world.

THE insistent demand created by the war for the maximum output of manufactured material in the minimum of time has naturally brought to the fore those means by which economy in production can be effected, and in this way standardization is coming into its own. Indeed, standardization in the engineering world has become almost a word to conjure with, but, like all good things, it must be taken in moderation, and the standards recommended must, by a process of periodic revision, be kept abreast of invention and progress; otherwise there is the danger of standardization becoming crystallization.

2 It may fairly be said that the primary objects of standardization are to secure interchangeability of parts, to cheapen manufacture

[1] Secretary, British Engineering Standards Association, 28 Victoria St., Westminister.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers. This paper and No. 1670 were the subject of a joint discussion which appears on page 887.

by eliminating the waste of time and material entailed in producing a multiplicity of designs for one and the same purpose and also to expedite delivery and so reduce maintenance charges and stores.

3 Seventeen years ago, however, neither the necessity nor the value of work of this character and still less its intimate relation to economy and speed of production was at all generally recognized, and it was to remedy the chaotic state of things then existing in the engineering industry of Great Britain that the late Sir John Wolfe Barry, K.C.B., F.R.S., in 1901 took the initial steps, when he brought the subject to the notice of the Council of the Institution of Civil Engineers, which resulted in the formation of the British Engineering Standards Committee.

4 From its inception certain definite principles have governed the work of the Committee, amongst which may be placed in the forefront the community of interest of producer and consumer, which is, in fact, the corner stone of the organization. It was also realized that the Committee should not be an academical body, but an industrial organization in the closest touch with practical requirements and modern scientific knowledge and discovery; that it should only undertake standardization to meet recognized wants, and then only at the request of the principal interests concerned; that it should confine itself to setting up standards, leaving it to the user to satisfy himself by inspection and supervision that the standards were being adhered to; and, most important of all, that periodic revision of the standards should be undertaken so that improvements might be incorporated, the various industries thus being prevented from becoming stereotyped and their methods hidebound.

5 From the small nucleus of seven members who formed the original Committee, a far-reaching organization has developed with some 160 committees, sub-committees and panels, including in all over 900 members and dealing under one central authority with standards relating to practically the whole field of engineering. Thus for many years past, the British Engineering Standards Association, as it is now called, has provided the neutral ground upon which the producer and the consumer, including the technical officers of the large spending departments of the Government and the great Classification Societies, have met and considered this subject of such vital interest to the well-being of the engineering industry of the country.

6 To the observance of the democratic and progressive principles outlined, coupled with the devoted labor of its members freely giving

heir time and experience to the work, often at great personal expense nd inconvenience, may be attributed the increasing success of this vork of growing national importance.

A large number of British Standard specifications and reports ave already been issued and these are constantly being added to, he most recent additions being the specifications for aircraft material nd parts drawn up at the request of the Department of Aircraft Production of the Ministry of Munitions, for whom the Association cts practically as the Departmental Specifications Committee.

7 The standardization of steel sectional material was the first vork taken up by the Committee. The British standards for this naterial, so important in the construction of ships, bridges and underrames for railway wagons, have had a very wide adoption. The otal number of sections is some 175, and the recently formed Mercantile Section of the Admiralty, as a war measure, was able to select rom this list a largely reduced number and so put into operation an xceedingly economical measure with but little delay. The testing equirements of Lloyd's Register and the other great Classification Societies and the Board of Trade have been unified through the work f the Committee.

It would appear from the steelmakers' returns for 1913, giving the onnage of lengths rolled of each section, that 95.7 per cent had been roduced by standard rolls and only 4.3 per cent by non-standard rolls, he work thus having proved of immense utility to the steelmakers.

8 In the case of tramway rails, standardization has had the esult of reducing to a minimum the sections required; at the present ime there are only five standard sections as against over 70 sections rior to the advent of the Committee. These sections are now being educed to three, one being a special section for interurban tramways perating at a higher speed than those of the towns.

9 As a further instance of the benefit of the Committee's labors ay be mentioned the Standard Specification for Portland Cement, hich is practically universally adopted throughout the country.

10 In regard to the electrical industry, the most important piece f work has been the issue of Standardization Rules for Electrical Iachinery, in the drafting of which much benefit has accrued rough the close and very cordial coöperation of the Standards ommittee of the American Institute of Electrical Engineers.

11 A large amount of standardization has been effected also for he automobile industry, especially in regard to the special steels used.

12 From time to time Government Departments have called

upon the Standards Committee to carry out work for them, as, for instance, in the case of the Ministry of Munitions in relation to the question of screw-thread tolerances and the gaging of screws generally. Then the Indian Government requested the Committee to undertake the question of standard designs for locomotives, and these have proved of immense value. The Road Board also asked the Committee to draft Specifications for Road Material. As already mentioned, at the request of the Department of Aircraft Production, the Association is dealing with the specifications for aircraft materials and parts as a war measure for the Department. To carry on this important work a large number of sub-committees have been formed, consisting of officers from the technical, supply and inspection departments, together with representatives from the various trade organizations concerned; the specifications in this case are not published by the Association in the ordinary way, but are issued to the Department of Aircraft Production, by whom they are sent to the various manufacturers of aircraft material on the Government list, in this way becoming obligatory.

13 In regard to the question of finance, the funds for carrying out the work of the Committee have been provided by the Government and the industries concerned. In 1903 the Government included in the Estimates a substantial contribution, which was subsequently extended for the years 1904–5–6 by a Grant-in-Aid equal to the amount contributed by the supporting institutions, manufacturers and others. This was continued on a smaller scale down to 1916, and a further grant on the same condition is being continued to March, 1919. The Indian Government has been a generous supporter of the Committee and the governments of other Overseas Dominions have also given financial assistance. A liberal response to the Committee's appeal for funds has been made by the engineering industry of the country and also by railway, shipping and other companies, and by some of the Local Government Boards and the tramway and electricity authorities.

14 The expenses of the whole organization up to the war were under £4000 a year, but, owing to the widening of the field of its labors, this amount has been very greatly exceeded.

15 The Committee, as many are aware, has recently become incorporated as an Association, under license of the Board of Trade, in order to enable it in the first place to continue the work carried out by the Engineering Standards Committee, viz., to coördinate the efforts of producers and users for the improvement and standardiza-

tion of engineering materials, and, secondly, in order to secure undisputed legal right to its mark or brand to be attached by manufacturers to their products as a hall-mark of goods made in accordance with the British Standard Specifications.

16 The chairman of the Association is Sir Archibald Denny, Bart., who succeeded the late Sir John Wolfe Barry, to whose guiding hand during the many years of his chairmanship, so much of the success of the movement is due.

17 The Main Committee, as the governing committee is called, consists of members nominated by the leading technical institutions, viz., the Institutions of Civil Engineers, Mechanical Engineers, the Iron and Steel Institute, the Naval Architects, and the Institution of Electrical Engineers; there are also two representatives of the Federation of British Industries; and three members, not representative of any institution or association, but elected for their eminence in the profession.

18 The members of the Federation of British Industries give the various trade organizations connected with the work of standardization a direct channel through which to place their views before the Main or executive Committee of the Association.

19 Rotation of office is provided in that the chairman and vice-chairman and one-third of the group of members retire annually, being eligible for reëlection.

20 The Main Committee is the sole executive authority and all specifications and reports are presented to it for final adoption. The procedure before embarking on any new subject is to ascertain by means of a representative conference that there is a volume of opinion favorable to the work being undertaken. If such is the case, the Main Committee nominates the chairman of a Sectional Committee to take up the work in question, this Committee being formed of technical officers representative of the various Government Departments interested, representatives of the trade organizations concerned, and lastly experts in the subject to be dealt with. The Main Committee does not dictate in any way either the number of members or the personnel of the Sectional Committee, only reserving to itself the right to nominate the chairman, though naturally it is guided in this matter also by the advice of the members.

21 Although the activities of the Association have in the main been confined to the home country, a considerable amount of work of an international character has been undertaken. At the present time the Association is coöperating with the American Institute of

Electrical Engineers in several directions in regard to Electrical apparatus generally. Then there is the great question of the standardization of screw threads and also of milling cutters and small tools, in connection with which The American Society of Mechanical Engineers will be able to render most valuable assistance. Indeed, there is a wide field for Anglo-American agreement on engineering standardization generally and the Association looks forward to a large measure of intimate coöperation with this object in view.

22 In connection also with its labors outside the home country, the Association is developing a scheme for assisting in procuring the wider dissemination of British Standards, and is undertaking the translation of its more important reports into various foreign languages, as well as setting up, with the assistance of the Overseas Department of the Board of Trade, Local Committees of British Engineers and Traders in some of the more important trading centers of the world.

23 That the value and utility of the work of the Association is becoming more and more recognized both at home and abroad is evidenced by the amount of new work it is continually being invited to undertake as well as by the inquiries received from all parts of the world both with reference to the Standards and to the organization itself.

24 The most recent addition to the Association's activities is that of the standardization of the details in the construction of ships and their machinery. A conference recently convened at the instance of the Board of Trade, and representing Government Departments, shipowners, shipbuilders and engineers, classification societies and consulting and naval architects, has unanimously decided to recommend to the Main Committee the setting up of a complete Section to deal with this branch of engineering, in which, in common with all others, economic production, fostered by interchangeability of detailed parts, is of such vital importance.

25 This brief account will, it is hoped, be sufficient to show that throughout the Empire, British Standards are receiving increased recognition as being of direct utility to the engineering industry generally. Standardization, after all, is no more and no less than proper coördination. To effect it, may necessitate the sinking of much personal opinion, but, if its goal, through wideness of outlook and unity of thought and action, is the benefit of the community as a whole, standardization as a coördinated endeavor is bound increasingly to benefit humanity at large.

No. 1670

THE WORK OF THE BRITISH ENGINEERING STANDARDS ASSOCIATION ON SCREW THREADS AND LIMIT GAGES

By Sir Richard Glazebrook,[1] C.B., F.R.S., Teddington, England
Non-Member

In the following notes the author gives the résumé of the work done by the British Engineering Standards Association in connection with limits and limit gaging, dealing more especially with the case of screw threads.

Report No. 20 of the Committee on Screw Threads and Limit Gages gives the standard dimensions of the two series of screw threads, British Standard Whitworth and British Standard Fine, and also of the British Association Series.

With reference to securing interchangeability the Committee has arrived at the conclusion that the fit at crest and root is in most cases unimportant and that the elements which do matter are the pitch, the effective diameter and, to a less degree, the angle.

As to the form of thread, the evidence collected showed that, provided no close limits are placed on the exact curvature at crest and root, the rounded Whitworth form has distinct advantages from the manufacturing standpoint. All tolerances are defined in terms of the pitch.

Much attention has been given by the Committee to the design and provision of gages for the full and core diameters, the effective diameter, the pitch, the angle and the radius. Satisfactory forms have been developed for all of these, except for the effective diameter, for which no simple device has been found as yet.

Six classes of gages are recognized: Standard gages, for depositing with a recognized authority; reference gages, for use by manufacturers; inspection gages, to check the accuracy of the work; shop gages, used in the workshop to control manufacture; check gages, for verifying the accuracy of other gages; and master gages, used only in the manufacture of, or for the purpose of verifying, check gages.

THE Secretary's memorandum to be presented at the same meeting with this contribution gives a résumé of the general work of the Engineering Standards Committee, now the British Engineering Standards Association. I have been invited to write some brief notes on the work connected with limits and limit gaging, dealing more

[1] Director of the National Physical Laboratory and Chairman of the Subcommittee on Screw Threads of the British Engineering Standards Association.

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

especially with the case of screw threads. This is less necessary in consequence of the admirable manner in which the screw-thread problem has been presented to The American Society of Mechanical Engineers by Mr. Bingham Powell; and again by Mr. Ehrman, who we recently had the pleasure of welcoming in England, in his article on The Screw Threads' Situation in Great Britain and America, recently read before the Society of Automotive Engineers.

2 The importance of problems dealing with limits and gages was recognized at an early date by the Main Standards Committee, which appointed a Committee on Screw Threads and Limit Gages in February, 1903. Two years later, after 23 meetings at which much hard work was done, the Committee issued its first report. Sir Frederick Donaldson,[1] Chief Superintendent of Woolwich Arsenal, was Chairman, while Colonel Crompton, Mr. Clements, of the Birmingham Small Arms Factory, and Mr. Taylor, of Messrs. Taylor, Taylor and Hobson, were leading members.

THREAD SERIES RECOMMENDED

3 The Committee made careful inquiries, studied the merits of other threads, in particular of the Sellers Thread, and finally decided that:

> Having regard to the evidence laid before the Committee, and to the fact that the Whitworth thread is in general use throughout the country, the Committee do not recommend any departure from this form of thread.

4 It appeared, however, that there was a very general demand for a series of screws having finer pitches than those of the Whitworth form, and this led to the introduction of the British Standard Fine (B. S. F.) series of pitches.

5 The report, No. 20, contains tables giving the standard dimensions of these two series of screw threads, B. S. W. and B. S. F., and also of the British Association (B.A.) series. It contains besides some definitions of terms which it may be useful to reproduce, since they differ somewhat from those in use in America.

Tolerance. A difference in dimensions prescribed in order to tolerate unavoidable imperfections of workmanship.

Allowance. A difference in dimensions, prescribed in order to allow of various qualities of fit.

Clearance. A difference in dimensions, or in the shape of the surfaces, prescribed in order that two surfaces, or parts of surfaces, may be clear of one another.

[1] Lost with Lord Kitchener in H. M. S. *Hampshire*.

Effective Diameter of a Screw. The effective diameter of a screw having a single ıread is the length of a line drawn through the axis and at right angles to it, ıeasured between the points where the line cuts the slopes of the thread.

Core Diameter. The core diameter is twice the minimum radius of a screw, ıeasured at right angles to the axis.

Full Diameter. The full diameter is twice the maximum radius of a screw, ıeasured at right angles to the axis.

Crest. The crest is the prominent part of the thread, whether of the male screw r of the female screw.

Root. The root is the bottom of the groove of the thread, whether of the male rew or of the female screw.

Slope of Thread. The slope of thread is the straight part of the thread which ɔnnects the crests and roots.

Angle of Thread. The angle of thread is the angle between the slopes, measured ı the axial plane.

Pitch. The pitch is the distance in inches measured along a line parallel to the ɪis of the screw between the point where it cuts any thread of the screw and the ɔint at which it next meets the corresponding part of the same thread. *The ɛciprocal of the pitch* measures the number of turns per inch or millimeter as the ıse may be.

No reference to tolerances or methods of gaging is made in this report.

INITIAL REPORT ON SCREW-THREAD TOLERANCES

6 The Committee next turned its attention to limits for plain ylindrical work, and a report on this subject, referred to in more de-ıil later, was published in 1906. In 1907 they issued Report No. 38 ı British Standard Systems for Limit Gages for Screw Threads. oth of these reports involved a long series of experiments and ıeasurements, many of which were carried out at the National hysical Laboratory.

7 The object of specifying tolerances was to secure interchange-ɔility, and a little consideration showed the committee that the ement whose error most seriously affects interchangeability is the tch; attention was drawn to the fact that the consequences of an ror in pitch manifest themselves not only in the direction of the ɪis, but also at right angles to it, and it was shown that with an ıgular thread of angle α a bolt and a nut of t inches in thickness, ıving a relative difference of pitch of p mils per inch, must have a fference of effective diameter of $pt \cot \alpha/2$ mils, in order that they ay go together; pt clearly measures the total pitch difference of the rew and nut in the length engaged, so that the importance of the tch error per length of engagement was appreciated from the com-encement of the work. In the case of the Whitworth thread, = 55 deg. and $\cot \alpha/2$ is approximately 2, so that we have the rule

that for a screw of faulty pitch to pair with a perfect nut, the effective diameter must be reduced by twice the pitch error per length of engagement.

8 In the words of the report, the Committee had before them two separate matters to decide:

a. To lay down tolerances on full core and effective diameters to cover the wear of tools and unavoidable imperfections of measurement, and to prescribe minimum allowances in order that bolts and nuts may be assembled freely.

b. To decide what errors in pitch could be permitted in ordinary practice, having regard to the allowances in effective diameter which they entail.

9 The report contains the answers to these questions. Formulæ are given for the various tolerances and allowances, and a table of values worked out for the two series of threads.

TABLE 1 BRITISH STANDARD WHITWORTH SCREW THREADS

TOLERANCES FOR BOLTS

Nominal Diameter of Screw	No. of Threads per In.	Pitch	Tolerance on Pitch per In. Length of Thread	Full Diameter. Maximum	Full Diameter. Tolerance	Full Diameter. Minimum	Effective Diameter. Max. for a Screw of Correct Pitch	Effective Diameter. Tolerance	Effective Diameter. Minimum	Core Diameter. Maximum	Core Diameter. Tolerance	Core Diameter. Minimum
In.		In.	In.	In.	In.	In	In.	In.	In.	In.	In.	In.
¼ (0.25)	20	0.05000	0.0035	0.2500	0.0018	0.2482	0.2180	0.0018	0.2162	0.1860	0.0022	0.1837
½ (0.5)	12	0.08333	0.0030	0.5000	0.0025	0.4975	0.4466	0.0030	0.4436	0.3933	0.0032	0.3901
1	8	0.12500	0.0025	1.0000	0.0035	0.9965	0.9200	0.0050	0.9150	0.8399	0.0045	0.8354
2	4.5	0.22222	0.0021	2.0000	0.0050	1.9950	1.8577	0.0084	1.8493	1.7154	0.0064	1.7090
3	3.5	0.28571	0.0019	3.4000	0.0060	2.9940	2.8170	0.0114	2.8056	2.6341	0.0078	2.6263

10 Table 1 gives the tolerances for bolts of ¼ in., ½ in., 1 in., 2 in. and 3 in. for B. S. W. threads.

11 It will be noticed that, except in the smaller sizes, the effective-diameter tolerance is larger than that on the full diameter, while in some cases it is larger than that on the core diameter. An attempt was made to get a comparatively close fit at crest and root, while less attention was paid to the slopes. The difficulty of gaging the effective diameter had something to do with this. The effect of error in angle was referred to, but not considered very fully.

FURTHER INVESTIGATION OF TOLERANCES

12 The matter remained in this state until comparatively recently. After Sir Frederick Donaldson's death, the committee

were reorganized; a Sectional Committee on Machine Parts, their Gaging and Nomenclature, was formed with Colonel Crompton as Chairman; screw threads are dealt with by a Sub-Committee on Screw Threads for all purposes and their gaging, and of this sub-committee Sir R. Glazebrook is chairman.

13 War conditions have increased enormously the demand for interchangeable screws, while the experience gained has enabled a clearer idea to be formed of the real essentials of interchangeability and of the difficulty of securing them. It has become increasingly clear that fit at crest and root is in most cases unimportant. Large tolerances can be given on these dimensions; some authorities think it desirable to prescribe actual clearances, i.e., to formulate such dimensions that the bolt and nut can never come into contact at these points. In any case, it is agreed that for the work,—the question of the gages will be treated separately,—an adherence to the exact amount of rounding at crest and root specified in the Whitworth thread is not needed. The elements which do matter are the pitch and the effective diameter: i.e., the lead and pitch diameter, to use the American terms, and also, to a less degree, the angle. The conditions applicable to munitions, guns, shells, fuses, etc., are somewhat special, and for these stores the possible tolerances have to be fixed in each individual case; but there is a very large demand for bolts and nuts, studs, and the like, using in most cases the finer series of pitches, and experience soon showed that the tolerances fixed in Report 38 were too small. These various factors led to a reconsideration of that Report, with the result that Report No. 84, on British Standard Fine Threads and their Tolerances, was issued in June last. Corresponding reports on the Standard Whitworth Series Threads, and the British Association Threads are in course of preparation, and it is hoped will appear very shortly.

FORM OF THREAD

14 While Report No. 84 was under discussion, the question of the form of the thread was considered with great care, and the committee had the advantage of discussing the series of pitches and other points of importance with the American Commission on Standardization of Aircraft Parts, then in this country, under the chairmanship of Mr. Diffin. It is a pleasure to acknowledge the help received from Mr. Ehrman, Mr. Hartness, Mr. Manley and Mr. Clarkson. It was clear to all that without deciding on the merits of the case it was impossible under existing conditions to alter the B. S. F. series of pitches, and it also appeared that provided the pitches were the same the 5-

deg. difference in angle between the English and American threads would not prevent a very considerable degree of interchangeability. This conclusion has been substantiated by measurements since made on both sides of the Atlantic.[1]

15 As to the form of thread, the evidence collected showed that, provided no close limits are placed on the exact curvature at crest and root, the rounded Whitworth form had distinct advantages from the manufacturing standpoint. Evidence for this is given in a paper C. L. 4102, Proposed Modification to Whitworth Form of Thread: Measurements and Mechanical Tests of Screws Made in Accordance Therewith. The alteration suggested was the flattening of the crests in accordance with the theoretical Sellers thread. Further experience and measurement show distinctly that in practice the crests of American threads are frequently rounded, while it is agreed on all sides that rounding at the roots is essential to strength. Rounding at the roots is produced naturally by the wear of a sharp-pointed tool, and it appears probable[2] that the radius selected by Whitworth (radius = 0.137 p, where p is the pitch), represents the stable condition reached by a pointed tool after some slight use. This point has been long pressed by experienced mechanics, such as Mr. W. Taylor, Mr. Sturdee and Mr. Dumas.

16 Much the same is true at the crest; the difficulty of making a die with sharp corners that will stand wear is well recognized.

17 The Committee, therefore, in drawing up Report 84, decided to adhere to the Whitworth form, but without insisting on the exact curvature at crest and root so far as the work is concerned. The case of a gage is different. Their conclusion runs thus:

> The tables do not specify tolerance on the form of the thread at the crest and root, but it is not to be inferred that the exact curvature given by the definition of the Whitworth Thread is necessarily to be adhered to. Fit at the crest and root is not ordinarily required in nuts and bolts, and so long as the diameters are within the tolerances shown the exact form of the curve connecting the crest or the root with the flank is immaterial, provided it is not such as to fall outside the boundaries of perfect thread forms defined by the limits of diameter given in the tables of tolerance. In the case of gages the theoretical form must be followed and attention given to the curvatures.

[1] See Report C. L. (M.) 5076, by the National Physical Laboratory, On the Interchangeability of Commercial Whitworth and Sellers Bolts and Nuts; also the interesting report and diagram, on the same subject, dated August 8, 1918, to be submitted by Mr. Bingham Powell to the U. S. Congressional Commission to Standardize Screw Threads.

[2] See Mr. Bingham Powell's paper on Screw Thread Angles.

TOLERANCES ON FORM OF THREAD

18 It remained then to consider the tolerances. Experience ıad shown, as already stated, that those given in Report No. 38 were oo small, while the measurement at the National Physical Laboraory of bolts and nuts made in the ordinary course of the work, and pecially of aircraft and other similar parts, during recent years, had fforded valuable information upon the accuracy attained by manuacturers, as well as of that needed for interchangeability.

19 In dealing with tolerances it is convenient, whenever possible, o base them on a formula connecting them with the other dimensions ın which they depend. For screw threads these are the pitch of the crew and the diameter of the cylinder on which it is cut; for a crew of given form the depth of the thread and the curvatures at rest and root are all proportional to the pitch. For the B. S. W. or 3. S. F. series of bolts and nuts the pitch is definitely related to the liameter, and it appeared best to treat the tolerances as depending

TABLE 2 TOLERANCES IN TERMS OF PITCH

	Full Diameter	Effective Diameter	Core Diameter
ıolt	$3 \times 0.01 \sqrt{p}$	$2 \times 0.01 \sqrt{p}$	$4 \times 0.01 \sqrt{p}$
Nut	$4 \times 0.01 \sqrt{p}$	$2 \times 0.01 \sqrt{p}$	$3 \times 0.01 \sqrt{p}$

ın the pitch only. Mr. Sears, Superintendent of the Metrology Deıartment of the National Physical Laboratory, was able to show that olerances proportional to $\sqrt{p}$, p being the pitch, agreed very closely vith those found to work well in practice over a large series of pitches, ertainly over the whole range covered by the B. S. F. and B. S. W. eries, and indeed some way into the B. A. series. He showed further hat the quantity $0.01 \sqrt{p}$, p being measured in inches, was a conenient unit of tolerance, and that the tolerances suitable for the 3. S. F. series were all given by some small multiple of this quantity. Accordingly, for ordinary work the Committee has specified the olerances as indicated in Table 2, while for finer work a table of close its, having half the tolerances of Table 2 has been adopted. These olerances are all negative on the bolt and positive on the nut, so that heoretically a bolt, if within the tolerances, should always pair with he corresponding nut, even if in the table of dimensions the maximum dimensions of the bolt are the same as the minimum dimensions of the nut, the dividing line being the theoretical form. But it is not

possible to secure this in all cases. The gages used to test the work have their own tolerances, and are also subject to wear. To overcome these difficulties, an allowance of 2 mils is specified everywhere between the largest bolt and the smallest nut.

20 It seems probable that in the case of the close fits at any rate this will need reconsideration; for many purposes it is more important to secure a tight fit than to have complete interchangeability among a large series of bolts and nuts; and, with the figures given in the table, when the maximum nut is paired with the minimum bolt, and the pitches and angles of the two happen to be identical, the fit will be a slack one.

TOLERANCES IN PITCH AND ANGLE

21 It will be noted that the tables do not specify tolerances in pitch and angle; it has been pointed out already that in the case of a bolt an error in pitch can be compensated by a reduction of effective diameter of approximately twice the total pitch error; an error in angle can be compensated in the same manner. The necessary formulæ are given in Report 84, Appendix ii. It is a necessary condition for a bolt, then, that the total reduction in effective diameter required to compensate the errors of pitch and angle must never exceed the permissible tolerance on effective diameter; a similar condition holds for a nut.

22 A simple graphical method for calculating the effective diameter equivalents of the pitch and angle errors has been devised by Captain Bishop, and is explained in the report, while a simple mechanism for applying Captain Bishop's method has been developed at the National Physical Laboratory. Denoting by x the effective diameter error, y and z the effective-diameter equivalents of the pitch and angle errors, Captain Bishop introduced the term *Grade* to denote $x + y + z$, the sum of these three; it will be found to measure the difference in diameter between the standard nut and a bolt of standard form which would just pair with a nut of the same dimensions as the bolt in question. The *play*, meaning thereby the lateral shake between the given bolt and a standard nut, is measured by $x - (y + z)$. For some purposes it is found convenient to specify screws by their grade and play. The grade indicates in a general way the difference between the bolt and the standard; the play gives a measure of the slackness of fit. For further details in regard to these terms, reference should be made to Report No. 84.

23 It has been pointed out already that the pitch error with which we are concerned is not the error per pitch or per unit length,

but the total error in the length of thread engaged; the error per pitch which is permissible then will depend on the number of threads engaged, and the manufacturer who desires to know whether a tool cutting threads with some definite errors per pitch will cut a screw up to the specification, requires also to know the length of thread engaged. This point has been well brought out by Mr. Green, of the Coventry Repetition Co., and the Committee are now engaged on a series of Tables intended to supply the necessary information.[1] The Tables will give the corrections to effective diameter required to compensate pitch and angle error.

STRESSES IN SCREW THREADS

24 Before leaving the consideration of the form and dimensions of screw threads, reference should be made to Mr. Rowland and Mr. Taylor's work, using Professor Coker's polarized-light method, on the stresses in threads of various forms. Strips of thin celluloid are cut to represent axial sections of a bolt and nut; these are placed together between crossed Nicols in a parallel beam of polarized light, and the colored patches shown, when they are stressed, give in a general way an indication of the distribution of the stresses. They show, as would be anticipated, the deleterious effect of a sharp angle at the root, and indeed generally that the distribution of stress is improved by increasing the angle of the thread, but it has not been possible as yet to get actual numerical results.

25 Professor Dalby has made a series of measurements of the strength of bolts of various forms, C. L. 3981. The general result appears to be that for a given angle the form of thread has no influence on the strength unless the root is sharpened when the strength is decreased. For forms of normal shape the 60 deg. angle is slightly, possibly 10 per cent, stronger than the 55 deg., but the amount is hardly sufficient to give a precise value without more work.

26 Reference should also be made to Mr. Stromeyer's theoretical work, summed up in a recent paper read before the Institution of Naval Architects, Stress Distribution in Bolts and Nuts.[2]

27 An admirable account of much of this recent work has been given by Mr. Bingham Powell in his Summary of Reports presented to the Screw Threads Committee of the British Engineering Standards Association.

[1] See Report C. L. (M) 5174.

[2] Tran. Inst. Naval Architects, Vol. 60, 1918.

GAGES AND GAGING

28 We come now to the question of gages and gaging; its importance and its difficulty have been before the Committee almost since its inception and the principles on which it depends have been often stated, by no one more clearly than by Mr. Wm. Taylor.

29 The gaging of plain cylindrical surfaces is a simple matter; to gage a ring a *go* and a *not-go* plug suffice; for a shaft we need either *go* and *not-go* rings, or *go* and *not-go* snap gages. But for a complicated form like that of a screw, the matter is far from simple; the screw is made up of many elements, and each needs separate consideration. A little investigation shows, however, that for exact work the go gage must gage all the elements simultaneously, while each element requires a separate not-go gage. Thus, for a screw we have as elements: Full diameter, core diameter, effective diameter, pitch, angle of thread, radius at crest, and radius at root; seven in all.

30 In symmetrical threads like the Whitworth the two last elements are the same. The go gage insures that the work nowhere oversteps the theoretical boundary; the not-go gages confine the tolerances on the various elements within the specified values. If interchangeability alone is to be gaged, and a more exact knowledge of the errors of the various elements is not required, the not-go gages can usually be reduced to the three first. The form at root and crest is immaterial, provided the full and core diameters are not too greatly reduced, the go gage insures that the standard boundary is nowhere overstepped. The go gage also insures that the reduction in effective diameter has been sufficient to compensate the errors, if any, in pitch and angle, while the not-go effective diameter gage provides that the effective diameter is not less than is tolerated in the tables. Thus, a complete go gage and three not-go diameter gages are needed.

31 Much attention has been given by the Committee to the design and provision of these gages, and Report No. 38 describes the system proposed by Mr. Taylor. It is easy to provide gages for the full and core diameters: in the case of plugs a simple ring, or a suitable snap gage, suffices; for nuts a plain cylindrical plug gages the core diameter; the full diameter is tested by a screw gage having one or two turns, with a very thin thread arranged to bear on the full diameter only. The effective diameter of a nut can be gaged by a screw plug of one or two turns, cleared at the roots, and with the crests ground off so as to bear only on the slopes of the threads; while for the effective diameter of a plug a ring gage bearing on the slopes only, or a three-point gage similar to Mr. Taylor's design is available

: A design of effective-diameter gage which is satisfactory and oo complicated has not, however, been found as yet, and the nittee are still giving the matter careful consideration. One of ifficulties is that of inserting the gage; an incorrect thread on a of work may be burred or contracted at the end at which the enters; it rejects the gage and is apparently correct, whereas, he gage passed the obstruction it would easily also pass the whole e rest of the screw, which should therefore fail. To overcome various forms of expanding gages are under trial at present. act that it is necessary for the go gage to be complete in all its nts adds greatly to the difficulty of making gages.

: It is sometimes suggested that in the case of a ring gage used lts it is sufficient to clear the gage at the roots of the thread, and : the full diameter of the work with an ordinary ring gage. In ase of the Whitworth thread with rounded crests this is inad- ble for two reasons: (1) There is no security that the work in the borhood of the crest does not overstep the theoretical shape, and is case it would not enter a nut of correct dimensions, and (2) e is no means of determining the concentricity of the various of the thread.

: In the case of a flat-topped thread, the first difficulty does not ; provided the parts of the thread are concentric the two gages the necessary boundary exactly, but the second difficulty still . Concentricity can only be tested by a gage of complete form, he construction of such a ring gage with flat roots is more diffi- han that of one with the roots rounded to the Whitworth curva- Difficulties were found during the early stages of our work in ning gages sufficiently accurate in this respect; it is remarkable well they have been surmounted by many makers, who now out most satisfactory hardened ring gages of high accuracy.

: English makers who have tried to make flat-topped screws in several cases found themselves up against the difficulty of ing concentricity when using a die with the roots cleared, trust- the original surface of the cylindrical bar to form the outer ce of the screw.[1]

: Methods of gaging such as have been described are practicable gh when dealing with a limited amount of work; they become us, and so far as effective diameter is concerned not very satis- ry when dealing with masses of stores as in munitions work or ordinary commercial supply of nuts and bolts. For bolts a

See Report C. L. (M.) 5076.

method of gaging by projecting the image of the work on to a screen carrying an accurate magnified drawing of the screw under test has proved rapid and effective and apparatus for this is in use in many factories.

37 Another method consists in keeping a careful watch on the tools employed, being assured that so long as they remain correct within certain limits the work they turn out will come up to specification. Most valuable work in this direction is being done by one of the sub-committees, the Panel on Taps, of which Col. Crompton is Chairman. The panel is investigating the methods of measuring taps, the conditions that connect the size of a tap and that of the hole it taps, the limits within which taps must lie in order to give specified results and the like, and in due time the result of the work will be available. The panel will also deal with dies and chasers.

TOLERANCES ON GAGES

38 Another series of questions is raised by the consideration of the tolerances to be allowed on gages; as a rough rule we expect these to be from $\frac{1}{5}$ to $\frac{1}{10}$ of the tolerances on the work. Their sign, however, depends on the purpose for which the gage is required.

39 In Report 84 six classes of gages are recognized, defined as follows:

Standard Gages. A standard gage is a gage made as accurately as possible to its nominal dimensions and suitable for depositing with some recognized authority such as the Board of Trade or the National Physical Laboratory for purposes of ultimate reference.

Reference Gages. A reference gage is similar to a standard gage, but is intended for use by manufacturers or others. Reference gages shall be verified, and their accuracy certified, by the National Physical Laboratory.

Inspection Gages. Gages used by inspectors to check the accuracy of the work and determine if it is within the limits laid down. They shall be verified and their accuracy certified by the National Physical Laboratory.

Shop Gages. Gages used in the workshop to control manufacture and verified from time to time either by comparison with reference gages, or by the use of suitable check gages. Alternatively, they may, if desired, be sent to the National Physical Laboratory for verification.[1]

The tolerances allowed on inspection gages should be such that all work between the limits of size specified will be accepted. This is insured by giving a plus tolerance to the *high* inspection gage and a minus tolerance to the *low*.

[1] The work is usually specified as lying between certain definite limits of size, and the various types of gages destined to insure this (Standard, Reference, Inspection or Shop Gages) usually take the form of *Limit* Gages. The *go* limit gage should control all elements of the work simultaneously. The *not-go* limit gages should be confined in their application to one element at a time.

The tolerances on shop gages should be such that all work passed by them is necessarily between the specified limits of size. To secure this the tolerances on the *high* shop gages must be minus and that on the *low* shop gage must be plus.

The tolerances on standard and reference gages are of the same sign as those on inspection gages, but are kept as small as possible in magnitude.

Check Gages. Gages used for verifying the accuracy of other gages. Generally speaking they are of opposite form to the gages they are intended to verify, e.g., the check for a ring gage is a plug, and vice versa. Check gages may be urther subdivided into standard check gages and shop check gages, following the lefinitions given above.

Master Gages. Gages used only in the manufacture of, or for the purpose of verifying, check gages. They are again of opposite kind to the check gages, and in some cases standard or reference gages will serve as master gages. More frequently, however, master gages, when required, have to be specially designed.

40 Inspection gages are used to see that the work when finished does not fall outside the dimensions allowed by the drawings. Shop gages are employed in the workshop to secure that the finished product shall pass the inspection gages.

41 Now it is a fundamental rule with us that the contractor shall have the full benefit of all the tolerance allowed by the specification; no work falling within the limits is to be rejected. Thus, if the limits for a shaft be 1.995 in. and 2 in. the ring gage used to pass the shaft must in no case be less than 2 in., the tolerance on this gage must be positive; it may be, say, between 2 in. and 2.0005 in.

42 Thus as stated above the tolerances on all high inspection gages are positive, those on low inspection gages are negative. But the manufacturer is anxious that all his work shall pass, he wishes to secure that his shaft is really between 1.995 in. and 2.00 in.; he requires therefore that the gage he uses to check its manufacture, his shop gage, shall be less than 2 in. How much less will depend on the amount he thinks he can safely spare from the tolerance on the work without adding unduly to the difficulties of manufacture; the tolerance on his high shop gage will be negative, its diameter may lie between 1.9995 in. and 2.000 in.; probably he would allow rather greater limits to permit of wear, but in any case the tolerance on the high shop gage is negative, that on the low shop gage is positive.

TESTING AND MEASURING GAGES

43 The demand for munitions gages has led during the past few years to an important development of the methods of testing and measuring gages.

44 Until recently gages of all kinds have been dealt with at the

National Physical Laboratory at the rate of about 10,000 a week; at present over 2000 screw gages are being tested weekly.

45 To describe fully the methods employed in this work would need another paper. They are dealt with in a pamphlet note on Screw Gages prepared by the Staff of the Laboratory.

46 Machines have been devised at the Laboratory for the rapid performance of the measurements required. In the case of a plug gage the diameters and pitch are all measured in suitable machines, the form of the thread is examined in a projection apparatus and the concentricity is tested by the use of a complete ring gage.

47 For a ring gage the diameters are checked by suitable go and not-go gages, the pitch is measured and the form is verified by taking a cast and examining it in the projection apparatus. A large staff, mostly of ladies, has been trained to carry out this work expeditiously and rapidly.

MISCELLANEOUS REPORTS

48 A very brief reference to other work on screws must suffice. Report No. 21 issued first in 1905 and since revised deals with pipe threads. These were the subject of various international conferences, and at a conference held in Paris in the Autumn of 1913 agreement was reached on a number of fundamental points and it was then hoped to issue shortly a report dealing with pipe threads on an international basis. This still remains to be done. Other reports have dealt with high-pressure copper tubing with screws for automobile use with spanners, sizes of nuts and bolt heads and the like, while a memorandum dealing with metric threads for aircraft purposes has recently appeared.

49 A list of the principal reports and papers is given at the end of Report 84 or in the Memorandum regarding the scope and purpose of the proposed Anglo-American Conference on Screw Threads, copies of which have been sent to The American Society of Mechanical Engineers.

50 One other matter of great importance has been raised lately, the question of threads for designed parts and their tolerances, and some progress has been made in considering this.

51 Mr. Remington has also raised the question of a reduction in the number of pitches in use with a view to the simplification of tools and gages. His paper on this subject, C. L. (M.) 3866 will be found most instructive. The matter is still under consideration by the Committee and on this point suggestions are desired.

52 I have dealt up to the present with the work on screws; the original reference to the Committee included limit gages for cylindrical work and some account of this seems called for.

ALLOWANCES FOR RUNNING FITS

53 The Committee when commencing the investigation found that there was practically no information as to the accuracy with which work made to drawings was being executed in the country. Some evidence was obtained by the issue of a questionnaire to manufacturers and others and at conferences called to consider the question. (It has throughout been the practice of the Committee to call into consultation representative manufacturers whenever possible.) The opinions received were conflicting in many respects and it was decided therefore to undertake an experimental investigation into the errors of workmanship actually occurring. This task was entrusted to the National Physical Laboratory and by the courtesy of some ten or twelve leading manufacturers, Mr. Attwell of the Metrology Department visited their works and made measurements of plain cylindrical shafts and holes from 2 in. to 12 in. in diameter. The results of these measurements are contained in the valuable Tables and Diagrams of Report No. 25, Report on Errors in Workmanship based on measurements carried out for the Committee by the National Physical Laboratory. This work permitted the Committee to draw up Report No. 27 on British Standard Systems for Limit Gages (running fits) issued in June, 1906.

54 Report No. 25 enabled the Committee to plot the difference in dimensions actually occurring in various grades of work and it was found that these fell in fairly well with a system in which the various differences of dimension when plotted against the diameter lay approximately on a kind of parabolic curve. It remained to apportion these differences between the shaft and the hole and to settle the allowances required for various qualities of fit and the tolerances permissible in various classes of work.

55 It was agreed to treat the nominal dimension as the dividing line between the hole and the shaft but there was much difference of opinion on the question whether the hole or the shaft should be the element most nearly approaching that dimension, i.e., whether to work on a shaft basis in which the maximum size of the shaft is the nominal dimension with a negative tolerance, all allowances being on the hole, or vice versa on a hole basis in which the allowances are on the shaft. The report was drawn up on the shaft basis. The maxi-

mum shaft has the nominal dimensions, the tolerances corresponding to three classes of work are all negative. The dimensions of the hole vary with the class of work and kind of fit required, the minimum hole will be of nominal dimensions + an allowance; the tolerance on this latter is positive so that the diameter of the maximum hole is equal to the nominal dimension + allowance + tolerance.

56 It was found possible to arrange the limits in such a way that the allowance for second-class work is the sum of the allowance and tolerance for first-class so that the diameters of the minimum hole second-class work and the maximum hole first-class work are identical. In this way it was hoped to reduce the number of gages required. It is also pointed out that the system can be reversed, the hole being made the basis and the allowances being made on the shafts. The tolerances tabulated apply only to running fits. The system has not made much progress, partly, it would appear, because in present circumstances it is preferable to make the hole the basis, partly perhaps because a system is required which will include push fits and force fits.

57 The matter has been taken up again recently; there are various systems already in use in England and the Continent. These are being compared and important memoranda have been drawn up by Mr. Hedley Thomson, Mr. Dumas and others; these are now under the consideration of the Committee.

58 It has been practically agreed, though no formal decision has yet been registered, to work to the hole basis; the facts that thereby the stock of reamers, etc., required is reduced and that shafts can be readily ground with high accuracy seem conclusive on this point, while no great difference of opinion is likely to occur in the majority of cases with regard to the values of the tolerance and allowances desirable; the various existing systems agree fairly well as to these and experience is decisive. It appears that for running fits the figures of Report No. 27 are fairly correct.

59 The main contention centers on the question whether to treat the nominal dimension as the minimum diameter of the hole or as its mean diameter. In the first case the nominal dimension would constitute the boundary between shaft and hole as in Report No. 27; all the tolerances on the hole would be positive, while in the second case the tolerances on the hole would be equally positive and negative the hole limits being

$$\text{Nominal dimension} + \tfrac{1}{2}\ \text{total tolerance}$$

and

$$\text{Nominal dimension} - \tfrac{1}{2}\text{ total tolerance}$$

or possibly the total tolerance might be divided unequally into positive and negative parts. The discussion on this question is both interesting and important and contributions to it will be most carefully considered.

IN CONCLUSION

60 Such in brief outline has been the work of our Committee for the past 15 years. I may claim, I think, that it has advanced in no small measure our knowledge of limit gaging. Many, alas, of those who shared in it at the beginning are no more. The names of our first Chairman, Sir Frederick Donaldson and our Secretary, Mr. Leslie Robertson will occur to all. To these must be added those of Mr. Clements, Sir Wm. Preece, Mr. Le Neve Foster, Mr. Henry Lea and others. To Mr. Leslie Robertson a great debt is due; his energy maintained the work, his tact smoothed many difficulties and his knowledge of engineering questions and engineers was of the utmost value. In Mr. le Maistre we have a worthy successor. Sir Frederick Donaldson was an ideal Chairman; keen and interested, with great knowledge and insight, a man of strong views but absolutely just and fair, anxious that everyone should have his say, that no decision should be taken without the fullest consideration, determined that the real wishes of the Committee should be clearly set out before any final conclusion was reached and that that conclusion should be definitely stated.

61 And if much has been done, there remains much to do in which we look for the coöperation of our American colleagues; the differences in practice, — it is too late to discuss them now, — though marked, are not, I trust, irreconcilable and it is to be hoped that the proposed Anglo-American Conference may solve the more important of these before the Committee of Congress, recently appointed to deal with the matter, makes its final report.

62 My services are at their disposal for this object.

63 Further information on the points dealt with will be found in the Memorandum regarding the scope and object of the proposed Anglo-American Conference on Screw Threads in Mr. Ehrman's paper on The Screw Threads Situation, already mentioned, and in many of Mr. Bingham Powell's communications.

APPENDIX

LIST OF REPORTS RECEIVED FROM THE BRITISH ENGINEERING STANDARDS ASSOCIATION

BY SUB-COMMITTEE ON SCREW THREADS

No. 20 (Revised Feb. 1913) Report on British Standard Screw Threads, February 1913.

No. 25 Report on Errors in Workmanship, July 1906.

No. 27 Report on British Standard Systems for Limit Gages (Running Fits), June 1906.

No. 28 (Revised Nov. 1908) Report on British Standard Nuts, Bolt Heads and Spanners, November 1908.

No. 54 Report on British Standard Threads, Nuts and Bolt Heads for Use in Automobile Construction, March 1911.

No. 61 British Standard Specification for Copper Tubes and Their Screw Threads, April 1913.

C. L. 3866 Copy of letter from Mr. Remington *re* Complete Standardization of Pitch in Relation to Diameter of Screw Threads, October 27, 1917.

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BY INSTITUTION OF NAVAL ARCHITECTS

C. L. (M) 4536 Stress Distribution in Bolts and Nuts, by C. E. Stromeyer, March 21, 1918.

BY NATIONAL PHYSICAL LABORATORY

Notes on Screw Gages by the Staff of the Gage Testing Department, enlarged issue 11, November 1917.

DISCUSSION

H. Bingham Powell.[1] The Anglo-American Conference on screw threads held in London early in the year was not able to arrive at final decisions, but useful work was done. In concluding the proceedings, it was agreed that the principal reports of the members of Sub-Committee on Screw Threads of the British Engineering Standards Association should be published in a summarized form in the United States — to present the views held in England on the advantages and objections to the angles, forms, pitches, etc., of the various thread systems in use.

I was charged by the committee to do this work and have presented the summary, together with some writings of my own on the subject, to the Standards Committee of your Society, and to the National Committee on Screw Threads.

The ideas held in England may be briefly presented as follows: The British Standard Fine series of threads is becoming very popular for ordinary engineering work. It has long been felt that the British Standard Whitworth Series and the United Standard Series — which are identical except for one size, ½-in. diameter — are too coarse for ordinary work; that is, contain too few threads per inch of length. On the other hand, they claim that the American Society of Automobile Engineers' series is unnecessarily fine for ordinary purposes.

The British Standard Fine series is almost mathematically a mean in coarseness to these mentioned, and so would seem to meet all common requirements.

It is most desirable, in many ways, that an international screw system should be adopted; and the feeling in England is that if we can agree in the matter of pitches, the form and angle of the thread can be allowed to take care of themselves; at least for the time being.

Although the form of the United States Standard thread looks so different on paper from the Whitworth form, in practice there is not much difference. The square top and bottom of the United States Standard are hardly ever found in ordinary commercial screws made by taps and dies, or rolled. The crests of the thread in a tap, or in a cutting or rolling die, very soon become rounded in use by the corners overheating and falling away — thus early

[1] Director of the Joint Gage Laboratories of the British War Mission and of the U. S. Bureau of Aircraft Production.

arriving at a radius which measurements show approaches the figure of 0.137 multiplied by the lead.

This is the proportion laid down for the Whitworth rounding. The latter would thus appear to be about the correct rounding with which a tool maintains a stable point.

Also, the roots of taps and cutting or rolling dies do not give a square form to the product — even if they are made of that shape — but a rounded form, similar in radius to the Whitworth. This is probably due to the fact that in such work the operation of forming the thread on the product is really partly that of extrusion; that being so, the square or sharp V-root is not suitable and the metal refuses to flow completely down in it, remaining rounded, as stated.

Thus we do not differ much over form; but should it be really considered necessary to give a complete solution to the problem, we could fix a "zone of tolerance of form" at the root and crest of the thread, to include both the nominal square shape and also the rounded.

About the angle of the thread: The variation of this actually found in the product is so great that the nominal difference of 5 deg. between the U. S. Standard and Whitworth threads is not of great consequence. We have conducted many experiments in our laboratory — and in England also they have extensively investigated the point — and we find that with the same pitch the average Whitworth bolt will assemble in the U. S. nut, or vice versa, either freely or using a light wrench.

Wm. T. Magruder (written). If another set of standard sizes of screw threads is to be added to the variety now in use in engineering construction, it is to be hoped that it will be done very advisedly and with full consideration of the materials that will be employed and the uses that will be made of the threaded members. It can probably be shown that there are more miles of bolt threads cut per annum from ordinary steel bolt stock than from any other one material or for any other one use. While special threads may be desirable for automobile tool-steel threaded members and for the bronze screws of astronomical and physical instruments, the thread upon which civilization rests and progress depends is the screw thread used in bolts and screws in general engineering machinery. It is therefore of the greatest importance that standards of materials, shapes, sizes, limits, and the like should be decided on with great care and that no radical changes be made in present practice except after

ery serious consideration of the millions of dollars of expense and ndless confusion involved in any such change. Experience gained ı changing from one standardized thread to another, and later to nother in engineering manufacturing work, leads me to speak ositively on the subject.

Any committee having this matter in charge should decide on ·hat may be considered to be standard engineering materials, and hould then experiment upon the relative strengths and fatigues f the threads made of these materials in machines simulating actual se. By strength is not meant solely the tensile strength of the hreaded member, but rather the strengths in tension, torsion and hear. One of the experiments which we have our engineering tudents perform at Ohio State University is to test ordinary commercial steel machine bolts by screwing the nut up with a wrench nd to see that they usually fail by stripping the threads. This vould indicate that the pitch was too fine or the fit too loose.

For the last four years screw-threaded members as used on ıunitions have been forced to the forefront of our attention. Now hat we are again to allow the manufactures of peace to lead the way, nore thought should be given to the commercial needs of this branch f engineering practice. The accuracy demanded and obtained in Government work does not always obtain in commercial work.

While full credit should be given to Sir Joseph Whitworth as eing the first one to bring order out of screw-thread chaos and to uccessfully standardize British screw threads, it should be borne n mind that the Whitworth screw thread is very difficult to dupliate, an expensive thread to make as far as accurate taps and dies re concerned, and still more difficult and expensive to cut with ccuracy in the lathe. It therefore seems the part of wisdom, now hat the International, French and United States screw threads are ll of the 60-deg. Sellers type of thread, to retain it as a standard hape — at least until something better can be devised.

E. H. Ehrman (written). Obviously the two main points of ifference between the British and American screw threads for contructional bolts rest in (1) the pitches of the finer series and (2) the ontour of the crests and roots.

With reference to the first point, the difference is in all probbility the result of looking at the matter from different viewpoints. The British feel that one series of pitches serves satisfactorily for all grades of work, whereas in the United States we feel that require-

ments are better met through a dual system of pitches. Had the British held our view, or, conversely, had we held the British view, the few differences that might occur in the resulting British and American series could easily have been adjusted through conference.

With reference to the second point and with special reference to Pars. 15 and 33 of Sir Richard Glazebrook's paper, I would offer the following comment: The time has come, I believe, when we must, in a specification, do more than prescribe the profile that forms the ideal boundary between the external and internal thread. We should specify the maximum tool profile, i.e., that profile of the tool which when new will produce a screw with the deepest root and the highest crest; as well as profiles of the "go" gages, which should be so shaped that the product gaged by them will not trespass upon the standard profile. Provision is thus made for a definite maximum clearance at the crest and root, and also for wear of the crest of the tool.

My experience with reference to the action of the thread tool at its root does not agree entirely with that of the author. Outlines of screw threads, both external and internal, on an enlarged scale of 50 : 1 indicate that the thread tool at its root suffers very little if any wear in service, as the crests of the thread are fairly true to the theoretical profile where it has been entirely formed by the thread tool. Where the bore of the nut has been enlarged and the outside diameter of the screw has been reduced so that the threading tool removes nothing from the crest of the resulting thread, the metal at the edges of the crest, instead of being removed, is built up or spun up, so that they are slightly higher than the surface at the middle of the crest. Observation also shows that the thread tool has under such conditions cut the thread fairly concentric with the bore of the nut and the body of the screw.

With the provisions made for clearance as cited above, I believe (1) that considerable eccentricity of the thread with reference to the bore or body diameter is permissible and (2) that much latitude may be allowed with reference to the shape of the tool crest. In fact, it is immaterial except as to the relative "life" of the thread tool, whether the crests of the tool be of the Sellers or Whitworth shape. My personal experience, however, is the ground for my preference for a thread having flattened crests and roots. The reasons for this opinion are given in the report referred to in Par. 63.

CHESTER B. LORD (written). Threads at best are a debatable and theoretical subject of which more is guessed at than known, and

f which figures do not tell all that should be said. At the beginning f the war the Bureau of Standards was asked to devise means of hecking gages, and with its usual thoroughness at once developed xcellent means of measurement; but unfortunately no gages that vere manufactured could pass their tests.

Eventually, however, such progress was made in thread-gage nanufacture that today almost perfect gages are turned out; but to vhat end? Threads have not improved nor the method of making hem, and again in our gages we have far outstripped our ability to nake threads. There seems to be no reason for making the proluction of threads more costly than at present, since they are satisactory as regards strength; and even if they were not satisfactory he gage would not definitely tell us so.

I can recall no other place where the gaging of a piece is made nore severe than required by the use to which it is to be put. For nstance, if we are to measure the outside diameter of a cylindrical ody, we do not use a cylindrical gage the height of the piece and set he piece in it; we use a snap gage or a ring gage. In the case of a hread, however, we make our gages at least one diameter thick — in ome cases more — and while we use a wrench for ultimately screwing lown a bolt and usually throw it out if it goes in by hand, we expect very bolt to go in the thread gage by hand and without force and nake no allowance for final screwing down, thus defeating the very bject we are striving for, to wit, a good-fitting male and female hread. I do not think it an exaggeration to say that if we had a erfect tap and a perfect die and took a bolt and nut that fitted erfectly in the gages, we would reject both. The inaccuracies or urrs are what make the apparent good fit.

Further, we do not cut a thread upon different kinds of material vith the same die. In manufacturing we have to deal with openearth and bessemer steel, brass and copper, which neither tap nor hread the same. Should we not then make our gages different for ach material? The number of good threads in a given lot of pieces nade with the same die or tap is dependent first upon the nature of he material used; second, the tolerance allowed; third, the method f relieving threading tools; fourth, the relation of the weight of the lie and the nature of the piece it is cutting; fifth, the mechanical neans used to cut; sixth, the nature of lubricant used.

In a mechanical sense the only part of the thread that is vital s at or near the pitch line. Still, inspectors have insisted upon 100 per cent height of thread because the draftsman so pictured it

and it has been necessary to make taps and dies to cut as the gage demanded, rather than to make them as they should be.

Another fact to be considered is that in most other things we usually gage only finished parts. We never think of holding to close limits on a roughing cut, but still we insist upon doing so on a thread which is precisely a rough cut as it is made with a tool which lacks the necessary clearance, rake, and rigidity.

Another point which shows the fallacy of our thread-gaging methods is that many threads enter the maximum gage with difficulty the first time and shake the second time. The answer to this, of course, is that the threads are rough at first and fit the gage snugly. In the process of trying them in the gage, however, they become smooth and where gaged a second time are a loose fit. This is more particularly true of brass. Also, using a ring gage often takes off the point of the thread so that it will not pass the test.

In practice it is usually the difference in the lead between the male and female thread that makes the fit. We make our gages accurately in this respect and then find it is impossible to procure taps and dies anywhere near as accurate.

The question of lead and angle has never been considered so important as since we entered the war. I think it may be stated without exaggerating that there are not a hundred lathes in the United States having lead screws of identically the same characteristics, considering as a basis the degree of accuracy used by the Bureau of Standards in measuring gages. This being so, it follows that it is impossible to get taps from different makers, or even from the same maker, which will check up accurately with a gage made by some one else.

With the introduction of the wire method of measuring, it is now necessary in cutting a thread to figure out in abstruse mathematics the angle the thread tool should have in order to generate a thread of the required angle and pitch diameter.

The question then naturally arises, Are we not making our threads to conform to the results secured by wire measurements, and misleading ourselves as to the angle and pitch diameter obtained? Are we not taking the wire system as an end and making our threads conform to the wire rather than using the wire as a means of measurement? In other words, we do not know whether we are getting the correct angle and pitch diameter with our wires, but we make our threads conform to them, nevertheless, and I contend that the wire system of measurement should be used for duplication only and not to set standards.

When the cross-section of the thread of a gage is projected on a screen the surface is shown to be full of hills and valleys even when ground — quite often the tooth is rounded. The object of the projectoscope is to indicate whether or not the tops of these hills constitute the desired angle. It is obvious that in using wires one may rest in a valley and the other on top of a hill — which shows the fallacy of attempting to say that a thread is 0.0002 in. or 0.0003 in. undersize or oversize on the pitch diameter. We do not know that we are measuring on the pitch diameter, which is simply a mathematical point of departure where two theoretical circles touch. This definition is necessary in order that the draftsman may generate his threads; but it has no place in the mechanical measurement of threads.

It may be asked why a thread is not as readily measured on the pitch diameter by the wire method as is a gear, where the method originated. The answer is that on a gear the wire has a long bearing on a finished, smooth surface with the tool marks parallel with the wire and much finer in proportion, giving it a true seat. It would not be attempted to measure helical or bevel gears by this method. It is obvious that the only way to do this would be with a ball and not a wire. This same is true of helical threads.

Many thread gages have been rejected because they were 0.0002 in. off on the pitch line and when this occurs it begins to tax our credulity as to the ability of the man to make these measurements, since we know that on a straight, flat piece two men can seldom measure within 0.0002 in., even with the same micrometer, the difference being due to the difference in pressure and feel. Of course here again we must not confuse the facilities of the Bureau of Standards with those available to the tool manufacturer doing war work.

When we consider that 0.0001 in. on the wire used for measuring a 32-pitch thread makes a difference in angle of 0.5 deg., we can see to what unnecessary refinement we are carrying things when gages are rejected that show more than 10 min. error.

The question of the maximum diameter is always a subject of discussion and dispute. Most drawings call for a theoretical 100 per cent thread or leave it to be inferred. In practice in the past we have been able to secure 75 to 85 on bessemer rod; from 85 to 90 with open-hearth rod and 90 to 95 on good brass. With the thread miller it is possible to get 75 to 85 per cent of pieces with 100 per cent thread, but fine threads usually require burring; and it is also in some cases possible to get a 100 per cent thread by cutting a slot in

the bottom of the thread on the tap, thus allowing the metal to flow.

Having hypothetically gone to the practice of milling our threads and having secured thereby what by individual measurements we call a 100 per cent thread of the proper lead and pitch diameter, and having also secured from the Bureau of Standards a gage as near perfect as they can manufacture, what will the gage tell us with regard to the thread? It does not tell us whether the thread angle is too small nor whether the pitch is correct. It does not tell whether the outside diameter is too small. It simply tells us three things: (1) whether the outside diameter is too great, (2) whether the bottom of the thread is oversize, and (3) whether the lead is correct.

I am assuming that the above was a maximum gage. Adding a minimum gage would establish only one thing more; i.e., the minimum outside diameter.

The shape of the thread to be adopted is another subject of discussion which is mostly futile. Some advise U. S. Standard thread type, others V-threads, when as a matter of fact both actually get on fine threads a Whitworth type, caused by the corners of the die wearing and the dragging of the material when the die becomes dull. This shows the advisability of divorcing theoretical mechanics from practical results.

I have stated that if we had perfect gages and a perfect nut and bolt, we would reject them when we came to use them. So, logically, if perfection is not satisfactory, less than perfection must be. We may lay it down as an axiom that two threaded pieces the angles of the threads of which are the complement of each other, cannot, if made correctly, produce a tight fit. What is required is to place enough metal on the male member to fill the female threads, and by this process any desired fit may be secured.

JAMES HARTNESS, commenting on the remarks by Mr. Lord, said that the purpose of gaging was to determine the character of the fit. It was necessary to measure the screw thread before it entered under the stress of its work, and the gage was supposed to indicate what the fit would be when the screw was under stress, for the special work to which it was applied. He hoped later to present a communication to the Society on the phase of this subject,[1] and for the present would merely say that the work of the projection lantern as it had been first worked out under the auspices of the National Physical Laboratory,

[1] Optical Projection for Screw-Thread Inspection, J. Hartness, MECHANICAL ENGINEERING, February 1919, pp. 127–135.

and as it was being carried forward by the Bureau of Standards, promised to bring us one step forward in the art of making screw threads. The projection lantern was destined to take a place in every plant, for it would indicate not only the profile of the thread formed but its pitch and diameter, and by rolling the screw thread in its cradle any irregularities in thread form and roughness would be indicated.

E. J. Bryant[1] said that it should be remembered that the purpose of a screw thread is to bind parts together. As a manufacturer of threads, gages and other parts, the thing which seemed to him to be vital to consider was what the standard of variation should be from the pitch or effective diameter of the thread. Knowing that, it would be possible to make gages that would check the parts, and to make parts to these gages which would interchange with the parts made by other manufacturers.

Comfort A. Adams, Chairman of the American Engineering Standards Committee, spoke of standardization as a basic matter of the greatest importance, and of the work of standardization contemplated by that Committee, which was organized in October, 1918, and consisted of three members each from the American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, the American Society for Testing Materials, the War Department, the Navy Department and the Bureau of Standards.

In the operation of the Committee a standard proposed and accepted as desirable is referred to the sponsor society, which appoints a Sectional Committee representative of that society and of other interested organizations, roughly in proportion of their interest. The personnel of that committee is referred for approval to the American Engineering Standards Committee. When so approved the committee goes to work and evolves the standard, refers it first to the sponsor society, and then to the Main (A. E. S.) Committee. When approved by both bodies, the sponsor society is granted the right to have printed on the pamphlet of issue the statement — "Approved by the American Engineering Standards Committee." Thereby that standard became an "American standard." The American committee has been in the closest touch with the British committee, and in the future it is hoped that the two committees will work in the closest coöperation.

[1] Supt. Small Tools Division, Taft-Peirce Mfg. Co., Woonsocket, R. I.

No. 1671

LABOR DILUTION AS A NATIONAL NECESSITY

By Frederick A. Waldron, New York, N. Y.
Member of the Society

In order to meet the increased demands for labor, which were greatly increased at e outbreak of the war, the Government of Great Britain established a Bureau of abor Dilution and commissioned it with the distribution of labor in a manner to lieve skilled workmen of the performance of those functions of their task which could accomplished by less skilled workmen.

The author, after referring to the work done by this Bureau, outlines in a general ay the scope of labor dilution as a necessary application to the national resources the United States.

He proposes the standardization of engineering products, the coöperative effort legislators and engineers, the education of the public to a mental attitude of basic onomy, and a redistribution of occupations according to adaptability, as steps conibuting directly or indirectly to the elimination of useless and unnecessary labor.

THE term Labor Dilution originated in England shortly after the declaration of war with Germany. Its original applicaon was intended to carry out in effect what the word "dilution" terally implied, namely, a thinning or spreading out. As applied labor it means the thinning out or spreading of the functions of e skilled workmen among those that are less skilled, and a Bureau f Labor Dilution was therefore established by the Government to ipervise and carry out its requirements.

2 The original objective of this bureau was to relieve the illed workman in the performance of certain functions of a task d employ less skilled workers for the purpose of accomplishing given task in a shorter time.

3 The development of the work of this bureau has been such at economies heretofore unknown have been established and e fact brought before the manufacturer in evidence strong and yond contradiction that many things done for apparent necessity ere not at all necessary to the proper and efficient conduct of

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business. Its work, during the war period, will become a national industrial asset and change the entire mental attitude of the employer and the employee to one of greater coöperation and higher efficiency for years to come.

4 Unintentionally, perhaps, and unconsciously, this bureau has created an element in labor dilution which was not included in the original program, as it has already established in the minds of the consumer that waste of labor and materials is the greatest foe to labor dilution that a nation may have. This is a vital problem and it is the engineer who must solve it in a scientific and satisfactory manner.

5 This paper is intended to outline the breadth and scope of labor dilution as applied to national resources from a broad rather than a detailed viewpoint.

6 For years following the war our usual ideas and whims will change and must be sacrificed to the needs of world economy and welfare. That which is done will be done in a way to conserve and profits will become secondary. This will involve the engineering of men and materials in its broadest meaning, since the supplies of both have become so seriously depleted through the waste of war.

7 When peace, prosperity and plenty prevail, there is an increased desire for ease, luxury and opulence on the part of those who have accumulated wealth; and for lighter burdens and greater pay on the part of the workers. There is an inclination by all to neglect, to a certain degree, their moral and patriotic responsibilities.

8 During the past 50 years the conservation of national resources and economies in their production and use have been sacrificed in this country for financial gain. During the past 15 years however, the mental attitude of the people has been undergoing gradual change toward economies that must necessarily develop as we take a stand in the world's progress and uplift.

9 Ultimately it must be "the survival of the fittest." nation's industries must be those for which it is particularly adapted they must be conducted in the most economical manner, and facilities for vending and transporting their products must be on an equally economical basis. For products of equal quality, those having the lowest unit costs will naturally maintain commercial and industrial supremacy.

10 National resources have no commercial nor financial value when lying dormant. There is no value in any natural resource until labor has been expended in its conversion to the use of man.

:he nation, therefore, which can deliver to the consumer its con-
erted natural resources in the minimum time with the least ex-
enditure of human energy is the nation which will lead the industry
nd commerce of the world.

11 To accomplish this means a most broad and comprehensive
ational policy in the organization of our legislative, banking,
usiness, agricultural, transportation, mining and manufacturing
olicies.

12 As the value does not appear until labor has been applied
o nature's labyrinth of wealth, it is incumbent that the study of
abor requirements and performance from the natural state to the
nal use, be given most careful consideration.

13 Labor dilution should include the questions of the func-
ionalizing of the work of the skilled operative for the less skilled
perative, the eliminating of all work except that which is absolutely
ecessary to produce the results, and the economizing in the use
f the necessities of the day.

14 The conditions which are confronting us at the present
ime will confront us with still greater force during the period of
djustment to peace conditions. They can be briefly summarized
s follows:

a The equipment and physical condition of our transportation facilities are not being kept up to the pre-war standard. This will be cumulative and necessitate a large force of labor to restore the pre-war condition of efficiency

b Agricultural industries are suffering for the lack of labor and intensified productivity of soil

c Our roads and highways are rapidly deteriorating due to the lack of man power to construct new and repair the old roads

d Work on the enlargement and development of public utilities is practically at a standstill

e Irrigation projects are practically stopped

f The manufacture of munitions, when abandoned, will place an immense amount of machinery in the scrap heap. This must be replaced by new machinery

g Operations in the erection of buildings other than those required for immediate war needs have practically ceased

h The output of our steel mills has been practically absorbed by the Government for war work

i Immigration has practically ceased.

j The birth rate will supply but a small per cent of the man power needed.

15 From the enumeration of the above items, it can be fully appreciated that the accumulation of work to be performed is stupendous. Therefore, if our present methods continue, the great problem will be to obtain labor for this work.

16 Without being pessimistic at the outlook, it would seem fair that the facts should be faced and preparation made along the lines of labor dilution to successfully cope with the situation.

17 The seriousness of the situation can be realized by quoting a few statistics. The high tide of immigration to this country was reached in 1913 and 1914, during which period 1,300,000 immigrants came to this country, of which it can be assumed that 900,000 to 1,000,000 were males of workable age. Of this number, 23 per cent came from Austria-Hungary, 23 per cent from Italy, 21 per cent from Russia, 8 per cent from Canada, 6 per cent from England, 3 per cent from Germany, 2½ per cent from the Scandinavian Peninsula, making a total of 86½ per cent. The remaining 13½ per cent came from all the other countries of the world. It is interesting to know that less than 17/100 of 1 per cent came from Holland, France and Switzerland.

18 From 1914 to 1917 over 800,000 immigrants came to this country, a number which is materially offset by the return to their colors of many immigrants of the pre-war period. During the year 1918 immigration to this country practically ceased.

19 This country is dependent almost exclusively on immigrants for common labor in mining, agriculture, steel making, road building and the development of public utilities.

20 It is self-evident that we cannot depend on European immigration to this country for this period. The depletion of man power due to war losses and the demand for this power in the reconstruction period abroad combined with the internal development that is likely to take place in Russia will mean that emigration from these countries will be prohibited. Further, of the man power sent by this country to Europe at least ten per cent will be incapacitated for work of a strictly laboring character.

21 We will therefore be practically dependent upon native-born Americans, based on our population of 1900 to 1905, which is estimated as ninety to ninety-five millions.

22 The best available statistics at the present time would indicate that the average birth rate of this country is 25 per thousand population and that the death rate is 15 per thousand, leaving a net gain of 10 persons per thousand. This would mean that there would annually come to workable age in the post-war period about 900,000, of whom approximately 400,000 would be males.

23 The influence of our educational institutions and personal liberty have probably created in the majority of those coming of workable age a desire for work of a higher character than that of the ordinary laborer or mechanic.

24 A review of these figures would indicate that in order to meet the requirements of the post-war period it is most essential that careful thought be given to the question of labor dilution as originally applied, and that action be taken upon it at once; and that there be reinforcement of this application by the changing of the mental attitude of the consumer and the manufacturer in favor of the principle that whatever is made or used shall be such that it partakes of basic economy rather than of profit.

25 While the employment of an abnormal number of females as a war measure is right and justifiable, its continuation during the post-war period is problematical from the standpoint of the nation's man power.

26 This brings the subject of Labor Dilution as a National Necessity to a phase much broader in its meaning than that which was originally intended.

27 Broadly speaking, labor dilution should consist not only in the functionalizing of the work of the skilled man with that of the less skilled man, but it is equally important to eliminate useless and unnecessary labor which, at the present time, is deemed necessary due to the mental attitude and the habits formed in years of development and peace. It would seem, therefore, that the problem of labor dilution can best be approached by classifying into the following program:

STANDARDIZATION (Indirect)
- *a.* Legislative Methods.
- *b.* Business and Financial Methods.
- *c.* Transportation Methods.
- *d.* Mining and Agricultural Methods.
- *e.* Manufacturing Methods.

COÖPERATION (Indirect)
- *a.* Legislative Methods.

b. Capital and Labor.
c. Engineering Methods.

3 ELIMINATION (Direct)
a. Non-essential Statistical Work and Data.
b. Non-essential Office Work.
c. Non-essential Administrative Work.
d. Non-essential Sales and Advertising Work.
e. The Idle Citizen or Loafer.

4 EDUCATION (Direct)
a. Of the Legislator.
b. Of the Business Man.
c. Of the Engineer.
d. Of the Executives.
e. Of the Laborer.

5 OCCUPATION (Direct)
a. Analysis.
b. Distribution.
c. Localization.
d. Compensation.

STANDARDIZATION (INDIRECT)

28 While the final effect of standardization on labor dilution is indirect, this is the foundation on which it should be built. The principal divisions are outlined above and will be briefly analyzed in the order of their importance.

29 *a. Legislative Methods.* All laws regarding the conduct of business should be simple and direct and the purpose in view should be the eliminating from the honestly-conducted business, complications or hardships involving unnecessary expense and red tape; such laws to be drawn up with the hearty and consistent coöperation of the legislator, the business man, and the employee, with a view of making such laws as simple and direct as possible. With honesty of purpose and fair dealing on the part of all, there should be no serious difficulty in establishing laws that would be much more simple and uniform than those at present in force.

30 *b. Business and Financial Methods.* Where there has been rapid growth and an immense volume of business, it has necessarily carried with it an enormous labyrinth of complication, duplication and detail work, which requires the employment of a large number of non-producers to care for records necessary to deliver the raw material to the consumer. The result of standardization would, in a measure, automatically eliminate this labor and tend to reduce the cost of doing business.

31 *c. Transportation Methods.* The amount of labor involved n the transportation of raw material to the consumer, directly or ndirectly, is enormous. By the adoption of standard forms of arriers, and an improvement in the vehicles of transportation, vith improved methods of handling materials at the terminals, a reat amount of labor would be liberated for other work.

32 *d. Mining and Agricultural Methods.* The amount of labor mployed on this class of work could be greatly reduced by the ntroduction of new machinery and the perfecting of existing mahinery. In mining, great progress has been made in the reclaimng of what was once considered waste ore. Certain strides have een made in the agricultural field whereby the productivity per cre of ground has been greatly increased. This practice, however, as not been employed in a large number of the small areas under ultivation. Intensive mining and farming should be given more ttention.

33 *e. Manufacturing Methods.* The standardization of producion in our factories would eliminate a large amount of surplus naterials which are now carried in stock by the dealers, and would llow of interchangeability of parts that are most essential and nable business to be transacted direct with the consumer. This vould reduce the inventory investment of manufacturers and ealers, thereby reducing the number of pieces to be made and the abor applied thereon.

COÖPERATION (INDIRECT)

34 It naturally follows, that in order to obtain the benefits om standardization, coöperation should obtain to the fullest xtent; and, by continuous and systematic effort on the part of the egislator, the business man, the engineer, and the workman, the essentials under the head of Standardization would begin to prouce results.

ELIMINATION (DIRECT)

35 The natural results following standardization and coöperaon would be elimination, since many employed at the present me would necessarily be transferred to other lines of occupaon.

36 The general headings covering the classes of work eliminated re covered in the preceding classification.

EDUCATION (DIRECT)

37 Following standardization, coöperation and elimination, there should be a concerted effort to educate to a new epoch of economy. The term Education as applied to this particular phase of the situation is used as an expression for the change of the mental attitude of the public from that of extravagance to that of basic economy. It should teach that "Waste makes want, and want makes woe" and that the conservation of our present energy and natural resources is of greater national value than the unlimited accumulation of the almighty dollar.

OCCUPATION (DIRECT)

38 Last but not least, occupation should be considered in the problem of labor dilution. An era is approaching in which the conditions of the present and past will be entirely changed. This new era will involve a wholesale change in the distribution of occupations. In order that this may be done with the least disturbance, a careful analysis should be made of the adaptability of the individual to the occupation and consideration should be given to the distribution of individuals to such occupations. Coincident with this should follow the locating of industries at such points as will insure economic production.

39 The occupational problem that will ensue will always lead to differences of opinion, but it is governed largely by supply and demand and the standards of living in different communities or nations. The lower the standard of living, the lower the compensation for labor. The higher the standard of living, the higher labor compensated. The problem, however, resolves itself into the production and delivery to the consumer at the lowest possible cost with a fair profit to the manufacturer.

40 These are facts showing that "a condition and not a theory confronts us. If it is expected to keep in circulation the currency of the world at the present rate, it is necessary that public improvements, manufactories, agricultural and mining interests, should continue at a rate commensurate with the present circulation of money."

41 This means a gradual readjustment and, in order to be prepared for this readjustment, the problem should be looked squarely in the face and the way paved by which such readjustment can be made with the least possible disturbance. This can only be done by careful planning and action on the part of the country's

greatest men in preparing to meet the problem of labor dilution in a broad way.

42 The English, with their customary conciseness, have expressed in the two words "Labor Dilution" that which it would require volumes to describe or discuss.

A study of the problem indicates that, in its broadest meaning, Labor Dilution and the Engineering of Men are practically synonymous, since the former involves all that the latter implies.

DISCUSSION

JAMES F. JOHNSON (written). Dilution of labor at this particular time is not a national necessity. Had the war continued and men been drawn from our factories, this country would have been obliged to face the situation, no doubt, as did England, France and Canada. To cope with the matter of dilution in this country there was established at Washington, under the Department of Labor, what was known as the Training and Dilution Service. Through this Service some 200 training departments were opened up in various manufacturing concerns engaged in making war materials. These departments diluted the skilled trades with men and women trained for their jobs through intensive training along the line of machine operating and specialized branches.

The problem now before the manufacturer is not "Dilution" so much as "Training." If the present wage standard is to be maintained and if the manufacturers are to care for home consumption and meet with the keen competition for foreign markets, which is sure to arise, the unit output of the workmen must be increased. This can only be where the workmen are actually producing during their full-day period and are capable of delivering up to capacity the production required of them. One of the principal elements entering into this increased production is that of thoroughly understanding how to perform the job. Unless the workmen have been previously fitted for the branch of work they are performing, they will necessarily have to be trained for it if best results are to be obtained. Such a training should be given in a definite and systematic way and should be coupled up closely with the production program of the factory. The U. S. Training Service has been rendering this assistance to many manufacturers and with its reorganization on a peace-time basis it is carrying on its program in even a more comprehensive way. It

has found that best results have been obtained where learners are trained upon production work according to the factory requirements and up to the same standards of the various branches into which the learners are to be transferred after training. Such training carried on in a large way would at least accomplish the more important results sought through dilution.

CHARLES E. FOUHY[1] (written). Except as applied to female workers, labor dilution has already had a fair start, notwithstanding the immense amount of constructive work that has been done through the Army and Navy instruction centers.

The Curtiss Aëroplane and Motor Corporation was one of the first to appreciate the value of maintaining a school for the purpose of training our female workers on exactly the same operations they would be expected to perform in the production departments. The success of this work is evident to all employers who have recently used women on operations formerly performed by male labor. They have made good, and it is the universal opinion that on many jobs women are better than men.

Will industry, now that it understands what results can be accomplished by labor dilution, revert to the old state of affairs? I think not. We have been accustomed to measure our needs by the other fellow's experience, but now it is plain to us it is not necessary to strive for the high standards of mechanical ability we have heretofore demanded.

For years we have overlooked a valuable source of labor supply right at our doors simply because we had no means of utilizing their labor. We have neglected to study the mental progress of semi-skilled and unskilled laborers. We have, without thinking, assigned them to the laboring positions, never giving them the benefit of an ambition to aspire for advancement.

During the past year our experience has been that men who formally applied for laboring positions were asking for machine jobs. In questioning them we found they had no special experience to qualify them for the important positions, and the result was that many of them were turned away. However, in the aëroplane business it was not possible for us to draw from an available supply of expert aëroplane mechanics, and there were operations where

[1] Employment Manager, Curtiss Aëroplane and Motor Corp., Buffalo, N. Y.

could take some of the brightest applicants and place them on work where they could, in a short time, master the details.

In looking back we recollect with amazement the avidity these men and women displayed when they were given a chance to break the bonds which held them in check. They have played an important part in the battle for liberty because they themselves have become liberated, and now that the war is over, are they to become an industrial asset or liability?

These men and women have had the benefit of specialized industrial training, and while they are not full-fledged mechanics, they are, nevertheless, better equipped to qualify for industrial work. The next question is, Are they going to be able to capitalize their experience? Naturally one would say, "Yes, if they can find the same class of work." I do not think this has any bearing in the case, because these people have demonstrated to their own satisfaction that if they can learn one job they can learn another. If this is not true, then has not all the study and work that has been put into labor dilution been in vain?

The force of habit in some concerns is bound to manifest itself in the readjusting period now before us, but large employers of labor who for the past year or more have spent a lot of time and money on intensive training are not going to set this all aside and proceed to hire and train their operators by the old methods. It is not necessary to prove to them how much it costs to replace workmen taken into the shop and turned over to a foreman on production work for instructions under the old system.

The soldiers and sailors who have been trained intensively in the various technical schools and manufacturing plants throughout the country, are they going back to their old line of endeavor, or are they going to follow the work in which they have been instructed? These men have received a training they never would have acquired under normal conditions. They have "found" themselves and are not going back to the old pursuits. Industrially they are an asset, and as such we are duty bound to provide them a means of livelihood.

The part that organized labor will play in this scheme must necessarily await developments, but we must not overlook the fact that Samuel Gompers, President of the American Federation of Labor, is the motive power which called into being the committee on Training and Dilution, responsible for the propaganda of specialized industrial training.

Even before the war employment managers were unanimous in the statement that there was a shortage of qualified mechanics. Manufacturers and employers of labor generally were responsible for this state of affairs, because when there was a mechanical position to be filled they demanded an A1 man for the job. We had long since given up the practice of the indentured apprenticeship, and it was not so much the question of where the man received his training as it was to get the right man. The idea of doing their part in replacing and developing the inevitable loss of expert mechanics due to old age and death did not concern them until the war came, and their best men either enlisted or were drafted into the Army and Navy. It was then the necessity of labor dilution manifested itself. Industry and the workers have benefited by the introduction of intensive training methods, and it is not reasonable to suppose they are going to turn their backs on a system which has enabled the Government to provide the sinews of war. We have taken a step forward which does not permit retraction.

THE AUTHOR. The remarks of both Mr. Johnson and Mr. Foy are very pertinent to one or two of the items mentioned in the paper and are interesting, instructive, and entirely true from their viewpoint. From the broader viewpoint, however, and looking ahead the conditions which will develop in the next quarter-century in this country, they lose sight of the broader phase extending beyond the factory walls and the factory schools into our national life. They fail to see that in order to keep our industries operating, our fields tilled, and our transportation facilities in operation, in addition to our former gain in population we have absorbed from a million to million and a quarter immigrants per year. This influx, however, has ceased, and before prosperity is in full swing it will in a measure be necessary to cover in word and action the entire program as outlined in the paper.

No. 1672

INDUSTRIAL ORGANIZATION AS IT AFFECTS EXECUTIVES AND WORKERS

By Charles E. Knoeppel, New York, N. Y.
Associate-Member of the Society

The reconstruction of the world after so many years of war must be based on efficient industrial organization. The type of organization required should be established along sound lines from a proper consideration of individual relations between men.

The author, from a studious survey of his experience as an executive, emphasizes as essentials in the formulation of definite laws of organization: The necessity of having an objective in the mind before beginning to work; the exclusive concentration of each man to definite functions; the avoidance of confusion and conflict of authorities; the proper division of departments in order to insure that each executive has complete control of all the factors affecting the success of his function; the creation of divisions which will develop specialists; the provision for permanency by training men to fill the positions of their superiors; the exact definition of the duties of each employee and of his relations to the others; the logical selection of personnel according to individual qualifications; and the creation of a standard manufacturing practice.

Valuable suggestions are also given in regard to the question of establishing an efficient administration. Delegating authority to subordinates, overlooking minor details, listening to wise counsel and arousing initiative in employees are recommended as important points in the exercise of industrial authority.

THE conditions found in the world after years of fighting are: Depleted treasuries; enormous debts requiring years, generations perhaps, for posterity to pay off; a world hungry for the food necessities of life; the most gigantic destruction of property the world has ever seen, making rebuilding a task that staggers the imagination; millions of the crippled, blind and helpless who must be taken care of in some form; other millions of people now directly or indirectly engaged in warfare, suddenly without occupation or immediate means of earning a livelihood.

2 To rebuild the world, for that is what is required, takes the whole thing out of the realm of cold reality and transfers it to the

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magination. Because we will confront problems, the like of which we never solved before nor ever planned to solve, there is little to go by — no charts, no sextant, no compass, no gages of any kind.

3 Yet we must find a way out. The world seems to be completely lost, but it cannot stay lost or we perish from the earth. Leadership and statesmanship of the highest type are needed as never before in the world's history. My sincere feeling is that we will have both, for I have an abiding faith in the principle that every crisis makes its own leaders in the workings of an all-wise Providence of which we may know nothing, but of which we are cognizant.

INDUSTRIAL RECONSTRUCTION

4 In order to work out the semblance of a logical or orderly basis for reconstruction, let me establish a few fundamental principles:

a To fill depleted treasuries, trade at home and abroad is necessary, and the basis of trade is industry

b For posterity to pay off debts in the form of taxation, industry must operate at a maximum, and the basis of industry is labor.

c To feed a hungry world the products of the farm are required, and to work the farms labor is necessary

d To replace destroyed and run-down property requires the products of labor

e To take care of the blind, crippled and helpless, is an industrial and therefore a labor problem

f To demobilize and dismantle our war machine requires the greatest amount of consideration from an industrial and therefore a labor angle.

5 It therefore seems that the basis of the reconstruction will be industry, with the foundation of industry being labor. In this connection let me state a principle which labor as well as capital must realize in the future: If a military war cannot be won without quantity production, a commercial war certainly cannot.

6 This all spells a better getting together between the employers on the one side and the workers on the other.

INDUSTRIAL DEMOCRACY

7 It must not take long for industrial democracy to become reality and it need not take long if we get down to fundament

principles and make every effort to secure the hearty coöperation of both sides in the industrial struggles we have so far had.

8 What do I mean by Industrial Democracy? It can be called "that condition in industry wherein both the worker and the employer work in harmony, coöperating each with the other on all matters affecting the management of industry, to the end that the public may ultimately secure the gains from a mutual consideration of rights and privileges."

9 Whether it comes sooner or later is largely a matter for the engineers of the land to determine.

10 There is another aspect that warrants our serious attention. The nations of the world desire to become trading nations because it is only through trade that money can be made. The nation that can win the most trade becomes the most prosperous. The one that is most efficient wins the most trade. Industry is the basis of trade with labor the foundation of industry. Hence, if labor is efficient, industry prospers, trade flourishes and money pours into the nation's coffers. If, therefore, this nation is to hold its own with the other nations of the globe, its workers and its employers must not refuse to work out a relationship which will make for prosperity and industrial success.

11 That we may have industrial democracy, that we may secure our share of the world's business so that our people may be both contented under the right form of government and happy in proper industrial surroundings, we must work toward a new objective in industry, which can be expressed as follows: To the worker, adequate wages to purchase the necessities of life and some of the luxuries; to the management, a reward in keeping with ability and effort; to capital, the proper return on investment; to the worker, management and capital, contentment and freedom from worry, pride in work and a liking for associates; to the consumer or public, products of industry of the highest quality and lowest cost. This all constitutes a type of organization, the ideals of which are the worthiest that can be imagined.

CHARACTERISTICS OF ORGANIZATION

12 Let me explain what I mean by organization. Everything that we do or say, everything that we use or make, is the product of the brain. In the last analysis the human being is the power behind everything. Organization, therefore, is the proper adjustment of the relationship between human beings, in an effort to

accomplish certain definite ends in life. If this adjustment is faulty, then we have an inefficient organization, incapable of making a success of what it undertakes. But if it is correct, logical and established along sound lines, then success is bound to result.

PROGRESS THROUGH ORGANIZATION

13 The progress of individualism through organization has come through four stages: First, the individual depending entirely upon its own efforts. Second, the appreciation of coöperation, when individuals sought others of their kind and formed communities. Third, the conception of the necessity of supervision to assure unity in purpose and action. Fourth, the conception of specialization and organization through proper coördination.

14 During these stages it was found that certain men were leaders and certain other men followers. The leaders found that instead of having each man do all the work necessary to maintain himself, greater results were obtained when some were sent to fish, others to hunt, and still others to till the soil.

15 It is this latter conception which has unshackled the human race from the bonds of individualism, for there is no task so stupendous that it cannot be divided into innumerable minor tasks, each of which can be efficiently accomplished by an individual. The science of organization can then be defined as "the process of dividing a complex objective into minor activities, each of which is well within the scope of individual effort."

INDUSTRIAL RELATIONSHIP

16 It therefore seems that before any discussion on organization as it affects executives and workers is undertaken, it is necessary to give better consideration than has been done in the past to what industrial relationship really means. This can be done by stating three self-evident facts:

a Industry is nothing but the acts of various individuals engaged

b Management consists of controlling and guiding the acts of the various individuals engaged in industry

c Industrial relations are the reactions created in all individuals, as a result of this control or guidance on the part of the management.

17 Having established these facts, the matter of the flow of influence in relationship is of vital importance and can be stated:

a Administrative Executives
b Operating Heads
c Superintendents and Foremen
d Workers.

18 With some idea before us of what industrial relationship and who influences the relationships between individuals, a brief ;atement of what influences these relationships seems necessary nd can be made as follows: Selection of men for definite tasks; ssignment of men to their work; method of instruction; rules and egulations in shops; methods in use; tools provided; equipment nd facilities furnished; condition of buildings; general surrounding; supervision; planning of work, standards of performance; ecords of performance; hours of work; plan of wage payment; ncentives; safety of working conditions and facilities; plant comforts nd aids; effect of conditions of work on health; educational opporunities; amusement opportunities; recreation; community interests nd management policies.

19 There are a variety of ways through which we influence ndustrial relations, as, for instance, personal contact and converation, bulletins, verbal and written instructions, things seen, criticism r praise, physical and mental influence and material or monetary eward.

20 In summing up it seems that ideal industrial relations an only be secured when those who influence them have a comlete appreciation of what influences relations and how they can be nfluenced, as well as a sincere desire to create such ideal relationship.

21 In attempting to work out this solution in a practical way ny conviction is: First, that all responsibility for proper industrial elations lies with the management and that all initiative and imrovement of these conditions must emanate from the management; econd, that welfare plans and schemes of profit sharing will never e effective unless they are built on the foundation of proper internal elationship between management, executives and workers; third, hat we secure efficient management and proper relationship only hrough efficient organization, controlled by well-defined policies, ntelligently applied by the executives in charge of the business.

22 I have repeatedly outlined the following as my ideas of he things necessary to consider in proper relationship from the tandpoint of the workers:

a The mental side of our workers must receive more attention than it has been given in the past

b We must eliminate strenuousness in work
c Force and drive must give way to leadership which inspires men to accomplish things
d The faith of man in men must be a greater part of our industrial life than it is today
e There must be a separation of the inefficiency of men and management
f More consideration must be given to the problem of increasing exertion
g Worry on the part of our workers must be eliminated
h There must be a more equitable distribution of responsibility
i The question of habit must receive proper consideration
j There must be a more intelligent selection of employees
k There must be fewer strikes and less industrial warfare
l Labor and capital must view things more from each other's standpoint
m There must be more attention given to industrial and vocational education
n Rest and fatigue must receive greater consideration
o Work that stimulates must take the place of enervating work.

23 At this point let me state a principle which is the result of my years of contact with industrial problems: In industry, the difficulties at the bottom, in the way of faulty relationship, industrial clash and inefficiency, are nothing more or less than the reflection of disorganization, lack of coördination and the absence of well defined policies at the top.

24 It is frequently stated that "There is plenty of room at the top," or, "It seems impossible for us to get competent men in this section," or, "The man is willing and a hard worker but does not seem able to secure results." In the majority of cases the fault lies not with the men themselves but with the organization and management.

LAWS OF ORGANIZATION

25 I became so firmly convinced that industrial success or failure depended entirely upon whether a concern was organized or disorganized that I have endeavored to reduce my experience and the experience of my associates to a concrete basis in an effort to establish the following definite laws of organization:

26 *The Objective.* A tentative plan of organization should be worked out and decided upon. Owing to the presence of unknown actors, which cannot be determined in advance, the ultimate objective cannot be agreed upon at the outset; in fact, it will be well toward he completion of the work before the final type of organization can be settled upon. No plan can be worked from the top down in its entirety, nor should one be worked altogether from the bottom up, or this would result in a development lacking coördination. The game should be one of "playing the ends against the middle."

27 *Greatest Complication.* A business or a department should be considered with reference to the most difficult functions which the men in charge will be called upon to undertake.

28 The evolution of industry from a one-man stage to that in which many men are needed for the handling of specific things, has been based, consciously or otherwise, on this "law of greatest complication." In manufacturing, for instance, there was no doubt a time when the same man could both design and sell what was to be made and then go out in the shop and make it. But as the knowledge required of a man to design, sell, and to make, became greater and more complete and intricate, it became necessary to form two sections or departments, each of which took over one of the functions named above. Each department was placed in charge of a specialist, and both departments were supervised by the man who formerly handled all the details himself.

29 This law that is involved applies not only with reference to a business as a whole, or to a single department of a business, but to any division of any department.

30 There are several reasons for establishing this law: First, to guard against putting more work on the shoulders of a man than he has the knowledge and ability to handle; second, to make it possible to pick out the hardest job first; to make possible the selection of that work which will yield the greatest returns in the shortest possible time.

31 In other words, the "law of greatest complication" demands that instead of trying to find a man who can handle all the work himself, it is better to create a department divided into the most difficult functions which the man in charge will be called upon to cover.

32 *Concentration.* Each section, division, or department of a business should be so arranged as to contain all the factors which will effect the performance of only its own function. If such a plan is adopted, the head of the work can be held strictly responsible

for the successful conduct of his department, as he controls all the factors in connection therewith and can therefore be given to understand that he will stand or fall according to his showing. The strict observance of this law when organization is being effected greatly reduces the amount of supervision required, and also tends to develop and strengthen the men in the concern.

33 *Individualism.* A battle cannot be won by half a dozen generals, all of whom have equal authority. There must be one-man control.

34 When a man enters an organization, his duties and all matters which he is to be held responsible for should be definitely stated to him. In addition, he should be told who the head is to whom he is responsible for carrying out his duties, as well as who the men are that will be responsible to him.

35 *Mental Capacity.* When a department or business is organized, a division should be made with reference to the knowledge and ability that will be required of the man who shall supervise the work, as well as with respect to the knowledge and ability that those men must have who shall actually carry out the work. Then, to what is to be done must be within the capacity of the average type of men who are fitted to fill the various positions.

36 If an organization is divided according to its most difficult function so that the knowledge required for each position will be as little as possible, and the positions are arranged so that each executive has complete control of all the factors affecting the success of his function, the executive positions, as a rule, can be well handled by average men.

37 *Specialization.* An organization should be divided so as to develop specialists. To this end, care must be taken that one department head shall not duplicate the work of another.

38 If the knowledge necessary to manufacture and market a number of products is divided up into a number of limited fields of knowledge, as it were, and one man is put in charge of all the work in each of these fields of knowledge, these men will become specialists. Now if, under each of these men, each of the sub-heads is in charge of all the work representing one portion of that field of knowledge, then there is an organization of specialists.

39 In an organization of specialists there is no difficulty in finding men to fill competently executive positions, for the average man with executive ability can handle efficiently a large amount of work in a limited field of knowledge.

40 *Responsibility.* An executive should be held responsible or the total proved results, or for inability to secure results, and ıot for the details of the methods that he uses in trying to secure hese results.

41 *Permanency.* In industry we find many cases in which no ›rovision has been made for training men to fill the positions of heir superiors, in case anything should happen to the latter. A nan may at any time be transferred, or he may die, or be taken ick, or resign his position, or take a vacation, or be dismissed from he employ of the company. In any of these cases, it will be the luty of some one else to fill the gap at least temporarily, perhaps ›ermanently, and if no one has been trained to take over the new vork, results are bound to be unsatisfactory, if not disastrous.

42 *Relationship.* A business is nothing more or less than the djustment of individuals, to the end that all may follow a definite ›olicy, or line of procedure. One of the weaknesses in business is he almost universal practice of giving an individual only the most ;eneral kind of instructions concerning what to do and how to do it.

43 A man is engaged to do a definite "something," and just vhat that something is should be known by all with whom he comes n contact; otherwise he cannot be held responsible for results. Iis function in the business, his duties in performing this function, nd his relation to others and of others to him, should be sufficiently efined so as to enable him to work efficiently.

44 *Personnel.* The question of selecting the personnel of an rganization and of training those who compose it should be given ery special consideration. Hiring men is, or should be, like purhasing materials, in that there should be, first of all, definite knowldge of what is required. After all, it is a case of matching qualifiations against requirements. For instance, if a position demands lose application, long hours, and indoor work, it is sheer folly to ngage a man who loves the open and therefore detests confinement nd close application. He would naturally be inefficient because liscontented and unhappy. If it is essential in buying a machine o lay down certain specifications, and then make sure that the machine measures up to them, it is just as important to have specificaions in regard to the men we shall engage, in order that we may check heir qualifications against them.

45 *Instructions.* Anything worth defining is certainly worth ecording and yet we have all seen organizations of people working ogether without any guide whatever in the form of standard practice,

no definite idea of functions and duties, no charts showing relationship.

46 The concern that insists on properly issuing complete written information covering the material it buys or the product it sells, should not deem it unnecessary to have written instructions and charts covering the operations of the people who use the material and make the product.

47 *Staff.* The average executive of a manufacturing plant is usually so engrossed in the routine of getting out production that he has not the time to make a detailed, painstaking study of the various methods and systems in his department, with a view to making any necessary improvements. It is for this reason that the use of staff men, who are kept free from routine duties, and who are able to devote their entire time to the study of one problem after another, has come into well-deserved favor.

48 The chief of staff should be a man of experience, tact, and exceptional analytical ability. Every department manager should have the right to call on the staff men to assist him in the solution of his problems, and to have them make detailed studies of any sections of his department that are not running satisfactorily. If the managers can be induced to make such calls on the staff freely, the results obtained will be satisfactory, but if staff advice has to be forced on them the results will be little. Staff consultation should never be forced on a manager except when the reports from his department show decidedly poor results and he does not call on the staff for assistance. In these cases it should be suggested that the staff assist him, and if he refuses to take the suggestion, he should be forced to accept their coöperation.

DEVELOPING INITIATIVE

49 With reference to these laws of organization for man-building as they pertain to the managers and executives, certain essentials have been discovered after a long study of the managements of industry. It has been found that the man with the highest type of initiative is the one who sees things to be done, without being informed, and who then delegates to others the task of doing the work. The man with the next highest type of initiative is the one who sees things to be done without being informed and who then does the work himself. The next in order is the man who sees things to be done, after being informed, but who does the work without being told. I need not mention any other classes.

50 In other words, a man's power in business is measured by the extent to which he induces efficiency in others and at the same time gives the least possible attention to duties other than his own. This is a good business law because while there is a limit to the amount of detail a man can handle, there is, however, practically no limit to the amount of supervision he can exercise, since in supervising he is merely guiding others.

51 No man knows what he can do until he has had a chance to demonstrate what is in him, and there is no man who is not able to do more than he believes himself capable of. I have time and time again found a man of only average ability who was a "leaner," but who developed unusual ability when given definite responsibility and the necessary authority whereby to get results, with the understanding that if he failed he should make way for some one who could "make good."

FUNCTIONS OF AN EXECUTIVE

52 A word at this point with reference to the functions of an executive seems in order. My experience has shown that the real functions are:

a To exercise general supervision over the business or the department

b To analyze results critically

c To put new problems before his men for their consideration, advice and action

d To criticize subordinates when results are not forthcoming, setting forth the reasons why

e To see that prescribed practice is lived up to.

MODEL ORGANIZATION

53 With reference to the type of organization through which we can secure the proper observance of the laws above mentioned, I feel that we have a perfect model which has never been improved upon since its inception — the human body — and if we go back to the human body as an example we cannot go far wrong in the development of proper organization.

54 The brain is the guiding factor or leader — chief executive of the bodily mechanism — a complex organization which is not in contact with the outside world and is not self-sustaining nor self-achieving. It simply coördinates and directs.

55 The five senses — taste, touch, smell, hearing and sight — are the staff organization or the advisers to the brain, and there are the voluntary and involuntary organs which carry out the instructions of the brain and maintain the bodily mechanism. This gives us the elements so often mentioned: Line as the performing and maintenance function; staff as the planning function; and the executive as the administrator.

RULES OF EFFICIENT ADMINISTRATION

56 In attempting to formulate rules of efficient administration. I have not underestimated the difficulties that follow from the fact that there is little in the way of prescribed practice upon which to base such rules. Nevertheless I shall endeavor to reach logically certain rules with respect to man relationships.

57 *Delegating Authority.* An executive should examine himself carefully, and frankly decide what his business capacity really is. Then he should analyze his work, classify it, and in three columns, A, B, C, list the various duties, in the order of their importance. The "A" duties he should attend to himself, the "B" duties he should delegate to his immediate subordinates, and the "C" duties he should give over to those in less responsible positions. The results accomplished, as compared with the old plan, would be tremendous.

58 *Details.* To fuss over details is to waste time that could better be devoted to more important matters. If you engage a man to do a certain thing, it is to be presumed that you have taken care to select the right man for the position you desire to fill. The man is expected to do a specific work, is responsible for the accomplishment of certain definite results, and therefore, has, or should have, certain well-defined duties to perform.

59 Nothing will so hamper a man as too constant supervision, designed to check him up minutely with respect to the details of his work, and if he is a real live, competent individual he will resent such a policy in time and seek employment where he can exercise his powers to the fullest.

60 *Contact.* The executive who disregards his immediate subordinates and deals directly with those immediately under these subordinates or with the workmen themselves, is unjust to the men whom he has placed in positions of authority.

61 *Change.* When new people are brought into an organization, due allowance should be made for the change in relationships that is necessitated.

62 *Counsel.* We grow in proportion to our acceptance of the teaching of those who, knowing more than we do about a given subject, can counsel wisely. Even now the value of the specialist n industry is an accepted fact, and as more of the younger generation take up executive work, the more widely will the importance of competent counsel be recognized.

63 *Approach.* There is always a right way to begin organization work, although there was a time when organization was a sort of "go as you please" proposition. Today matters are different. Those at the top are coming more and more to realize that they themselves are the ones who should recognize the need for betterment work, and that they should be willing to assist in such work with all the power of their influence and of their money. A large responsibility rests upon the board of directors. If the leaders n industry do not favor making beneficial changes, how can the workers be expected to be progressive?

64 Next in importance is the coöperation of the heads of the various departments, for it is these people who will have to do the greater part of the work under the changed conditions. With he heads of departments in line, it will not be long before the foremen will follow. After all, the real fault in industry is not so much with the workers as with those higher up; hence the logic of starting t the top in any campaign of betterment.

65 *Initiative.* The executive should study men in order that e may be able to arouse in them the greatest possible amount of initiative.

66 Carnegie adopted the right basis upon which to develop men. He did not care anything at all about a man who did not already look upon himself as a future partner in the business. Cultivate this ideal in your men, give them tasks that will demand all their reserve powers, and then watch them develop initiative.

67 *Progress of the Individual.* The executive should give his workers every opportunity to make good and win their way to positions of responsibility.

68 If the executive will apply the laws of organization which have been given, and especially those that concern mental capacity, responsibility, concentration, and greatest complication, he should be able to fill the higher positions satisfactorily with men from his own organization, instead of wasting time looking outside for ideal men.

69 *Executive Direction.* The object of administration should be to develop men.

70 The manager of the future will not be a manager at all, at least not according to the present interpretation of the term; he will be a coördinator and a guide. Primarily, instead of doing, he will decide; rather than counsel, he will seek advice; instead of achieving, he will endeavor to inspire others to achieve. He will not spend his time on details, he will delegate them to others. He will not be a driver, he will lead. Instead of looking at things from the standpoint of dollars, he will consider them from the standpoint of sense. In other words, instead of always asking, "How many dollars can I make," he will ask the more important question first of all, "How many men can I make?"

71 No matter how we study men, we cannot get away from the conclusion that the underlying motive which influences most of us is an instinctive desire for gain. We are all creatures of aspiration, and it makes absolutely no difference whether the person is the man who owns the large industrial enterprise, or the man who works by the day. Both want to make as much as they possibly can. To mutualize the interests so that each can realize his desire, is no easy task. It is not an impossible task, however, and in its successful performance both capital and labor will receive material benefit. Both lose out when either ignores the interests of the other.

THE PROBLEM OF THE COST OF LIVING

72 In conclusion let me ask this question: What is our responsibility? The cost of living is an important issue. Demand increases with the increase in population, and it is an established fact that supply has not been increasing with this increase in population. To get supply enough to meet the demands and to balance with cost of living, will not be such an absorbing problem. There are two possible solutions: 1, There must be more producers; 2, There must be a greater amount supplied by those now producing.

73 The first solution is practicable only if labor is allowed shorter hours, better working conditions, and a remuneration which will attract the worker. The second can be employed by eliminating wastes, standardizing conditions, bringing about proper coördination, setting fair tasks, and allowing men to earn an amount which will compensate them for their skill and their coöperation.

74 Let us not be satisfied with conditions as they are, but strive for conditions as they should be. In attaining this ideal all may assist, with the certainty of accomplishing something worth while. We cannot change yesterday. The past, with its mistakes

ıd its misunderstandings, is behind us. But, profiting by ex-
ɜrience, with the picture of the right ideal before us and guided
/ a keen sense of justice and fair dealing, we can dare to attempt a
ttlement of the serious problems of industrial life, and contribute
ightily to the progress of the world.

DISCUSSION

JOHN F. GRACE (written). The fifteen conditions stated by Mr.
noeppel in Par. 22 are almost axiomatic, but their application is a
gantic task for executive genius. To this end pictures and graphs
ould be applied as in the manner of good advertising to instruct
e workers rather than texts.

The lack of definite instructions to each worker which the author
entions as a major cause in the breakdown of organizations seems
rgely due to the inability of managers or systematizers to define
ıd isolate duties which they are constantly shifting and overlapping.

In addition to the charting, any radical change of system affect-
g the majority of workers should be explained fully and clearly
; a general meeting of the employees of the department or plant
fected by some one who understands both the object and method
the system and the viewpoint of the workers sufficiently to make
ear explanations and to answer questions.

It must also be explained why merely doubling the wages of all
orkers will benefit nobody in the end; that the world's greatest
ealth is its efficient workers and leaders of character and their
arcity its poverty; and that only by substantially increased pro-
ıction per individual can the workers of the world obtain for them-
lves better homes and more comfortable living.

DWIGHT T. FARNHAM (written). Industrial Democracy and the
uman Factor are slogans which must not remain mere phrases if
ıe country is to escape that period of chaos which has resulted,
nce history began, whenever a proletariat has been allowed to
ɜalize its strength. For more than two years labor has been king.
he workmen has been courted by every conceivable device from
igh wages to music and oratory. He has been made to realize his
ower as an economic factor and as a voter and he is not going back
) the bread line without smashing something. Whether he smashes
ıerely industrial imperialism or our whole industrial fabric rests

with the men who do the staff work for our captains of industry. Whether American industry reconstructs as a democracy or whether, lured by labor's temporary appearance at a disadvantage during demobilization, she attempts reorganization as an autocracy, depends upon the vision and force of the advisers who are in a position to influence the type of organization in the course of its evolution. The men who are to do this work must have trained minds. They must be experienced in analysis in accordance with the laws of the scientific method. They must have the personality to sell their conclusions to the workmen, to the foremen, to the superintendents, to the management and to the stockholders. Most of all they must know and believe in human nature. For a long time we have been advocating the replacement of authority by responsibility. The governments of the world are in the throes of this change. Industrial reconstruction comes next and the road of responsibility lies clear before the engineers of America.

A. C. Fleckenstein said that engineers engaged in production could help immeasurably the advance of industrial- and efficiency-engineering methods by creating in the mind of the owner of a plant a proper regard for the services of the apparently non-productive industrial engineer, an investment in whose services would render a large financial return.

No. 1673

NON-FINANCIAL INCENTIVES

By Robert B. Wolf,[1] Saulte Ste. Marie, Ont., Canada
Member of the Society

The author contends that creative work by the workmen in the industries is not only possible, but that with it there can be introduced a personal interest in the work alike beneficial to the employee and employer.

Accounts are given of instances where this has been accomplished, through supplying foremen and workmen with information upon costs, methods of operation, possibilities in the direction of economy and efficiency, etc. Progress records are also furnished so that the employee will know from day to day how he is improving in the mastery of the process upon which he is engaged.

Freedom to express one's individuality in constructive work, properly restrained by law, is considered by the author to be essential.

THE basis of all "non-financial incentives" is interest in work. Interest in work implies a desire to produce actuated by internal motives rather than external discipline.

2 Production means creation and the industrial creative function in man is a mental process and lies in his intelligent adaptation of means to ends. It is useless, therefore, to look for real creative work unless the workman has a chance to think and to plan; any other working environment either fails to attract or actually repels the workman, and as a consequence offers no incentive to increased effort.

3 Work which does not call for thoughtful reflection, and which uses only muscular effort, tends to draw man down to the level of the brute and makes for industrial irresponsibility and consequent social disorganization. The unthinking man cannot be a responsible man.

4 It is the self-conscious faculty of man which distinguishes him from the animal and makes him above all a creative center through which the universal life giving power can deal with a particular situation in time and space.

5 To use a homely illustration with which every one is familiar

[1] Manager, Spanish River Pulp & Paper Mills, Ltd.

Presented the Annual Meeting, New York, December, 1918, of The American Society of Mechanical Engineers.

— the traffic at each crowded street crossing cannot be regulated from the City Hall; it requires an individual (the traffic policeman) in the congested spot to deal with each particular situation as it arises, and upon his powers of observation and selection depends the orderly flow of traffic.

6 It is only through the individual life that the universal life can act and therefore the universal is compelled to evolve many individual lives if organization and order are to replace the unorganized state represented by the purely generic operation of natural law.

7 The problem of social organization is, then, how to organize society upon the basis of respect for the individual. This is also the industrial problem as well, for industry in the broadest sense is society in its highest form of activity because it is essentially constructive and therefore creative activity.

8 It was an inevitable corollary to the universal plan of creation that the individual life came into being not to create material substance, as that had to be before individual life could gain consciousness. The function of the individual life, however, is to create by a thought process conditions especially selected to produce results which nature unaided would fail to produce.

9 This is what the horticulturist does. His power lies in his knowledge of natural law and his creations are made possible because he conforms to the law. The uncultivated orchard reverts to its original wild state when no longer attended by man, but increases in productiveness by continued thoughtful application of man's power of selection and adaptation.

10 It is by a similar process of conscious selection that such devices as the steamboat, steam engine, electric generator, and the telephone came into existence. They did not come into being and never would have been created by the generic operation of nature's laws.

11 To illustrate further: the desire of the savage to cross a body of water too wide for him to swim caused him to observe the floating of things which floated naturally. As a result of this observation he built a raft; and finally, by further observation, he discovered the principle that any thing which, bulk for bulk, was lighter than the water it displaced would float, and although he perhaps unconsciously applied this principle, it is true that from its application he evolved the canoe.

12 It is by a continuation of the application of this same law that, almost within our own memory, it has been made possible for

the vessels of the world to be built of iron, something which the old shipbuilders thought impossible. We see then that it is the application of the personal factor that now makes iron float by the use of the very same law that makes it sink.

13 Upon a higher plane, the modern electric generator was evolved by observing that a wire passed at right angles through a magnetic field would induce an electric current to flow through it in a certain direction.

14 It was only by creating, through the application of the personal factor, conditions by which this law could be expanded that electricity was generated commercially. The electric generator is nothing more than a large number of such wires, insulated one from another, passing in and out of a number of magnetic fields, plus a device for collecting and conducting away the current generated. The important point to remember is that there never would have been an electric generator without the introduction of the individual personalities who literally created it.

15 In this connection it is well to observe that all of our creations, if they are to be successful, depend upon the strict observance of the laws of nature. When we clearly see man's place in the universal life movement we can understand why it was that in the long process of evolution it was inevitable that a being capable of measuring by reflection be evolved. The very word "man" is derived from an Arian root meaning to measure.

16 All this may seem at first sight far removed from the problem of "non-financial incentives," but it seems to me it is necessary before proceeding further to gain some conception of the reason for man's existence. The concrete illustrations of the operations of non-financial incentives will then have greater meaning.

17 Man, through the exercise of his intellectual faculties so laboriously acquired through ages of slow evolution, literally reflects the universal creative process upon the plane of the particular. There can be no organization of material substance except through an individual who can observe the laws inherent in the materials themselves. Then, by a process of reflection, these materials can be organized into forms which they could not take unaided by the individual will or a power external to themselves.

18 To state the matter more concretely: man, we know, cannot bring matter into existence, neither can he create the force which resides in the physical elements he uses in the day's work; what he does is to observe nature's forces in action and then, having learned

the laws, i.e., the reasons for their action in any particular direction, he seeks for means to make them express themselves more fully.

19 This, of course, necessitates the creation of conditions which do not occur spontaneously in nature. We have here the beginning of what we call the artificial and it is significant that the highest type of this form of creation, upon a higher plane than the natural, is termed art.

20 This creation of artificial conditions which, taken all together, we call civilization is of course the product of man's organizing power. While self-consciousness, the power of realizing the self as apart from the rest of the universe, has been a human faculty for untold ages before the present highly-organized state of society had been attained, it is nevertheless true that now, for the first time in the history of the white race, we are confronted with the problem of correcting the repressive or selfish character of civilization so that it will serve the mass of humanity. If we fail to accomplish this it will be destroyed by the same creative power which brought it into existence.

21 We must learn how to change the industrial environment from one which repels mankind to one which attracts. In other words, the incentive to work must be inherent in the nature of the work itself.

22 Now what are the conditions which we must meet in the industrial world to make work attractive? We have ample evidence that increasing financial returns have failed to stimulate productivity and, on the other hand, the constant demand for shorter hours and the increasing labor turnover is proof that work in most of our industries not only does not attract but actually repels the workman. We must therefore look into the working conditions themselves for the answer. This is the only scientific method of procedure.

23 I would like to quote from a letter received from a very intelligent labor leader recently,[1] to show how the mass of employees look at the problem and how urgent is the need for its immediate solution if we are not to have a greatly reduced production of the necessities of life brought about by the concerted action of the workers —

> Is it not true that the industrial evolution which has brought the trusts into existence has been the means of eliminating the "human touch" in industry? During the days of small industrial plants, the employer and the employee, of course, were really fellow-workmen. At the present time, however, the employee has perhaps never seen any of the stockholders of the industrial plant where he is employed.

[1] John P .Burke, Int. Pres., Pulp Sulphite and Paper Mill Workers Union

You say that: Men can be productive only when they take an interest in their work and they will not take this interest unless those entrusted with the direction of their efforts realize that they must teach them constantly how to exercise their creative powers.

While I agree with everything you say relative to creative work and have thought along these lines considerably myself, still, is it possible in industries, as they are constituted at present, to enable the average workingman to do creative work? Isn't it true that industry is becoming so specialized that the workman is no longer a creator? I realize that while it may still be possible for the workman doing certain jobs in the mill to do creative work, to a certain extent, still isn't the tendency of modern industry more and more toward making the workman simply an appendage of the machine?

In the paper you sent me, you described how you designed a plan for the men operating the hydraulic press to take an interest in their work. This certainly is a practical illustration of what can be done, and perhaps could be cited as a refutation of what I have just written above. I realize that there may be certain jobs in the mill where the creative powers can still be allowed to develop, and that the workman may be given a chance to express his individuality, but the point I am trying to bring out is that the tendency of *modern industry* is away from creative efforts and gives the workman less and less opportunity for individual development. When I worked in the factories, which I did from the age of 12 to 25, one of the things I found the most dissatisfaction with was the deadening sameness of the work. I never remember a time, when working in the factories, that I became so interested in my work that I didn't long for quitting time to come. After leaving factory work I got a job with a building contractor. As I became more proficient as a carpenter, I have time and again been put doing certain work that was more or less creative, in which I have become so interested that I paid no attention to quitting time and have worked for two or three hours after the time when I might have quit work. There is joy in creative work. But, in my opinion, no matter what schemes we will try to devise, modern industry is going to tend more and more to make simply automatons of men.

I may say, however, that I could find very little to criticise in either of your articles. You have demonstrated, from practical experiments, things that I have often theorized about. The conflict in industry during the next few years, in my opinion, will be between the democratic and autocratic ideas. The autocratic idea, I think, is best exemplified by the German military machine.

24 I was able to convince the writer of the letter from which I ıave just quoted that creative work could be done to a great extent ı modern industry, and, further, that this could be accomplished, vithout any radical changes in equipment, greatly to the advantage ıf both employer and employee.

INDIVIDUAL PROGRESS RECORDS

25 To do this, individual progress records are necessary so that the workman can know from day to day how he is improving in the mastery of the process.

26 The first example, illustrated by Fig. 1, is from that branch of the wood-pulp industry known as the sulphite process and shows

HOURS	TEMP	GAGE PRESSURE	STEAM PRESSURE	GAS PRESSURE
0		0		
1		20		
2		48		
3	212	75	0	75
4	222	75	3	72
5	233	75	7	68
6	240	75	10	65
7	250	75	15	60
8	259	75	20	55
9	273	75	29	46
10	288	75	41	34
11	284	57	38	19
12	281	40	35	5
13				

NAMES OF COOKS AND GENERAL INFORMATION FILLED IN HERE.

ACID TEST { Total 7.00; Free 6.05; Combined 0.95 }

Acid Temperature 75 Degrees Fahrenheit.

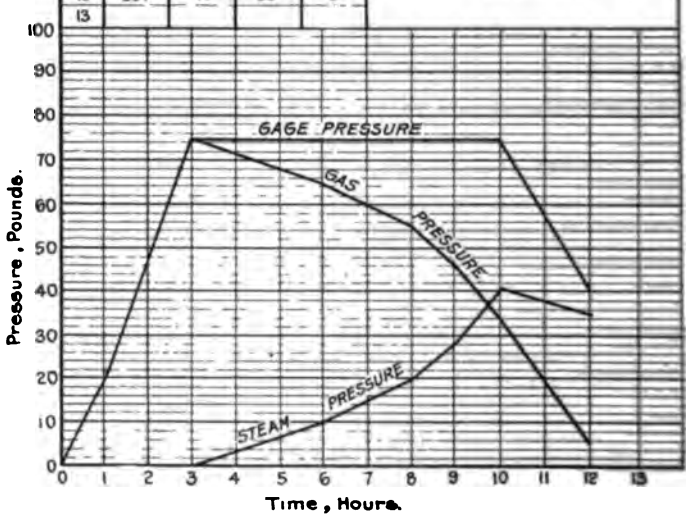

FIG. 1 REACTION IN DIGESTERS IN WHICH WOOD CHIPS ARE COOKED

a cooking chart which was designed to give the cook information about the reactions in the digesters in which the wood chips are cooked in a 6 per cent solution of sulphurous acid partly combined with a lime base.

27 The digesters have a conical top and bottom and are usually 50 ft. high by 15 ft. in diameter. After the acid and chips are put

nto the digester and the cover is put on, steam is turned in at the ›ottom and the pressure brought up to 75 lb. per sq. in. above atnospheric pressure.

28 As this does not heat the digester sufficiently to produce disntegration of the wood, it is necessary to relieve gas through a relief 'alve on the cover. Because of the removal of this gas, which is .fterward reclaimed, more steam can come in at the bottom and thus he temperatures are advanced. The skill in cooking consists in the ›roper control of the relief valve.

29 Before the introduction of these cooking charts illustrated by 'ig. 1, all this was left to the unaided judgment of the cook with ısually nothing to help him but a small hand thermometer and a ›ressure gage. Of course, great variation in the pulp was the result. The cooking charts, plotted by the cooks themselves, however, helped ;reatly as they enabled the quick visualization of the work. On hese charts temperatures are converted to pressures for the reason hat the pressure in the digester comes from two sources, one the ıatural pressure due to steam, and the other due to the sulphurousıcid gas. The pressure, for instance, which would correspond to a emperature of 212 deg. would be 0 or atmospheric, yet from the hart you will see that the gage pressure actually showed 75 lb. The lifference between 0 and 75, therefore, is caused by the presence of ulphurous-acid gas. As the cooking progresses, the gas is naturally ısed up; first, by being relieved for the purpose of making room for nore steam; second, by the natural combination of the acid with the ›rganic compounds liberated during the cooking process.

30 At the end of the cooking process the gage and steam pressures will naturally come very close together as the greater part of the SO_2 gas has been used. The gas-pressure curve is obtained by subtractng the steam pressure from the gage pressure. It is really a resultınt of the other two. If it drops too rapidly the cook knows he is relieving his digester too hard and checks the opening of the relief valve. If it does not drop rapidly enough he knows he must open the valve wider in order to increase the relief. Of course, the figures are taken from recording instruments which are checked daily to insure ıccuracy. Naturally, an ideal cooking chart was soon formed, being the joint work of the cooks handling the digesters and of the chemical research department.

31 Immediately after the introduction of these charts a very marked increase in the uniformity of the pulp was noticed, and the cooks, while at first opposed to the new method of "cooking with a

lead pencil" as they called it, soon learned to like their work much better for the reason that they now had some way of visualizing the work in its entirety. In addition to more uniform quality of the pulp, the yield from a cord of wood increased something over 5 per cent.

CONTINUOUS PROGRESS RECORD

32 We soon found that it was necessary to give some sort of continuous progress record if we were to keep up the interest in the work, because no man could carry in his mind anything but a general impression of his progress from day to day. Several good records for one day are only like so many good golf drives. They are a source of satisfaction at the time, but just as the score in golf denotes our real mastery of the game, so does the progress record measure the man's increasing mastery of his work, and we feel that it is one of the moral obligations of the management to keep such records for the individual workman. Without these records men will not think of improvements in the process and they cannot be blamed for becoming indifferent. How long, for instance, would a superintendent or manager retain his interest in the economical operation of his plant if his cost sheets were withheld? We, as executives, must have quantity, quality, and economy records, otherwise our interest soon lags. Why, then, should we expect the workman to be interested when he is not furnished with a record which at least reflects one of these elements?

33 Such records can be grouped, under three main headings: quantity records, quality records and economy or cost records. Quality records, which occupy the middle position, are, perhaps, of the greatest importance for they bring the individual's intelligence to bear upon the problem and as a consequence, by removing the obstacles to uniformity of quality, remove at the same time the obstructions to increased output. The creative power of the human mind is, however, not content simply to produce the best quality under existing conditions of plant operation. The desire to create new conditions for the more highly specialized working out of the natural laws of the process, demands expression and this expression at once takes the form of suggestions for improvements in mechanical devices.

34 This desire contains within it the germ of economic thought which will unfold and express itself eventually in a request for cost records, and the organization that neglects its opportunity to satisfy this desire is overlooking one of the great avenues leading toward intelligent productive effort

35 Because of the interrelation of quality, quantity and economy ecords, any complete record of individual progress must, of course, ake them all into account. However, as this is not always practical ve have at least one of three ways of measuring progress always open o us.

36 Table 1 shows how we keep a continuous progress record of he work which is mainly one of quality. By quality I do not neces- arily refer to the quality of the material produced, as most of our ecords refer to the quality of the work performed; in other words, he nearness to which the workman approaches the ideal standards vhich he has helped to form. The democratic coöperative forming of these standards by the joint work of the trained technician and the practical workman is absolutely essential, otherwise continuous progress will not be made. The whole plan must be really educa- ional in nature and to be so the records must record the natural laws of the process and the individual's degree of control of forces in the naterial elements that he is using. The more factors that can be ecorded, the greater the interest in the work. The reason for this is obvious.

37 Referring again to Table 1, it will be noted that there are nine nen cooking. These men are posted in the order of seniority, with he highest monthly record on top. There are three foremen at the op of the record. Each of these foremen has three cooks under him nd their standing is made up by taking the average records of the nen under them. In this way we are enabled to get not only the ndividual records of the men, but the group, or team-work records, s well. The lower group is merely for the convenience of the de- artment head in charge and gives the relative standing of the large, nedium, and small digesters. This is irrespective of the men who re working on them.

38 The total progress record figures in the first column are made p of the temperature, color, time and blowing records. The relative alues that these have in the total record are shown at the top of each olumn, the total adding up to 100. The small variation in the nonthly average column is characteristic of all our progress records, nd shows how great is the incentive when individual effort is in- elligently recorded.

39 The temperature record is obtained by taking half-hourly eadings from the recording-thermometer chart, upon which a tandard temperature curve has been plotted, calling each reading vhich happens to fall on the standard line 100, and a reading 20 deg.

TABLE 1 RECORDS OF INDIVIDUAL COOKS

Date, June 2, 1916.

Name	Total Progress Record		Relative Value 50		Relative Value 35		Relative Value 10		Relative Value 5		General Information					
			Temperature Record		Color Record		Time Record		Blowing Record		Average Maximum Temp.		Average Test 5th Hour 1.25		Average Test 6th Hour 0.80	
	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.	Daily Avg.	Mo. Avg.
Myler	88.2	88.3	84.8	85.9	99.3	98.3	90.6	88.6	58.8	59.5	293.6	294.7	139	134	100	103
Duggan	86.2	87.7	81.8	85.1	96.4	97.7	95.3	91.9	59.2	60.8	299.0	298 5	134	133	96	95
S. T. Ellis	85.8	87.1	79 1	83 2	98.8	97.7	95.1	93.8	57.9	59.7	299 8	299.6	125	129	101	102
Rodgerson	86.7	89.3	83.3	88.2	99.2	99.0	92.5	88.8	64.3	62.1	296.2	294.7	161	134	105	103
J. P. Ellis	89 5	88.7	87.2	86.8	96.7	97.7	96.7	94.8	56.3	62.0	294.7	297.2	123	129	94	96
McKee	88.8	88.3	84 8	86.0	100.0	98.9	90.5	90.0	56.4	59.9	294 4	294.7	132	133	96	101
Teeling	88.0	88.2	84.2	85.9	100.0	98.5	92.8	90.7	62.0	61.0	299.5	298.3	128	135	91	104
McKelvy	83.1	87.1	77.1	84.4	96.0	97.8	93.3	89.0	62.0	60.5	204.3	298.8	122	129	96	97
Element	84.9	87.2	79.1	83.8	96.7	97.7	95.2	92.2	59.3	59.9	297.8	299.7	130	131	98	95
McLean	83.9	87.2	75.3	81.9	98.8	99.1	97.8	93.3	59.2	57.8	306.4	302.1	137	134	109	102
Johnson	85.4	86.4	77.9	82.2	97.5	96.1	94 4	97.0	52.3	60.2	294.5	296.3	136	131	102	101
Neil	89.2	86.1	89.2	86.1	86.3	83.7	98.8	96.8	54.6	56.3	289.3	294.4	130	133	100	105
Large	86.6	87.4	82.0	85.5	98.5	98.3	91.9	87.0	59.8	59.9	299.0	298.4	129	133	95	100
Medium	87.2	87.9	83.3	85.7	96.5	97.7	94.9	91.8	58.6	61.6	298 2	296.9	134	132	99	99
Small	85.9	86.5	80.1	83.1	98.2	97.9	94.9	88.3	57 6	58.3	298 4	299.3	131	133	102	100

ither side of the standard line 0. This means that for each degree off of the standard, 5 points are deducted from the progress record.

40 The color record indicates how near the men come to blowing the digester when the color of the liquor shows the proper amount of lignine in the solution. The sample, drawn from the side of the digester, is compared with the standard color. To get a mathematical value for this factor a range of colors from a very dark to a very light was obtained, the particular shade which was taken as standard marked 100 and one shade either side 10 points less than 100.

41 The time record is obtained by calling a certain time of cooking 100 and taking off on each digester cooked one point for each minute above or below this standard.

42 The blowing record is obtained by calling 30 lb. pressure 100 (most of the cooking being done at a pressure of 75 lb. per sq. in.) and 60 lb. 0, the idea being to get the pressure as low as possible before blowing the digester.

43 It will be noted that the temperature value is higher than any of the others. This is because it is the most important element. The color record coming next in importance is given the next highest value, etc.

44 By an arrangement of this sort, by simply changing the relative value of the different factors, it is possible to emphasize any particular phase of the work. The men willingly pay the greatest attention to the factor that has the greatest value because it gives them the better record and because they know the reason for the change. For instance, if it is desired to emphasize quantity, we give a larger value to the time record and a lesser value to the temperature record. Production is then somewhat increased at the expense of quality.

45 While I could give many illustrations similar to the one just given of our cooking operations, I will give only one final illustration of how economy progress records meet with equally great response. In the plant where this system was developed were employed over 200 men and perhaps half of these men had individual progress records and the rest came under some sort of group-progress record. Invariably the records proved themselves to be an incentive to greater productivity.

COST RECORDS OF WORK

46 Below is shown a foreman's detail job sheet which indicates the method we had for giving our maintenance foremen cost records of their work. It is obviously a difficult matter when dealing with maintenance and construction work to give quality or quantity records as the work varies so much from day to day, so the only kind of records we could give the men were records of cost. The original suggestion to give these records grew out of the fact that we gave to each operating department head a complete cost of operating his

FORM NO.8

FOREMAN'S DETAIL JOB SHEET.

Job 2771 Foreman John Laffin Date 1/10/16

Name of Job Install 2-35 Hp. Motors on Coarse Screens in West Mill.

Description Electrical Dept. - Power Wiring.

Date Started 1/7/16 Worked on 4 Days

Labor Cost to Date 31.6

Material Cost to Date 7.38

Total Cost to Date 38.54

Labor Cost Yesterday 0.80

Material Cost Yesterday 6.41

Total Cost Yesterday 7.21

DETAIL OF MATERIAL USED YESTERDAY.

ITEMS.	PRICE.
2-1½" Long-Turn Elbows,	0.51
4½ lb Solder,	1.23
4-1½" Type E Condulets.	2.02
4-1½" 4 Hole Porcelains,	0.64
1 Roll Oiled Lined,	0.24
1 Roll Friction Tape,	0.11
16-100 Amp. Terminals.	1.66
	$6.41

FIG. 2 FOREMAN'S JOB SHEET

department for which he was held responsible. As soon as he be[illegible] to realize this responsibility, because all the repair materials w[illegible] charged to him, he at once began to make intelligent criticism of [illegible] engineering department, and especially was he critical of the main[illegible]nance foreman if he was wasteful in the use of materials. As a re[illegible] of this, the maintenance foremen asked the master mechanic if th[illegible] could not have job costs showing how economically they were do[illegible] their work as they had no idea of the value of materials that th[illegible] were using. The foreman's detail job sheet sh[illegible] is the result [illegible] this request. It will be noted that the job is fully described, the to[illegible]

cost for labor and material to date is given, as well as the cost of labor and material for yesterday. Then below is listed the itemized cost of all materials used. The men soon became educated as to the value of the materials they were using and we noticed a great change in the amount of waste; in fact, we had frequent cases where maintenance foremen would bring scales into the mill to make sure that the storehouse was giving them full measure of materials and we were soon

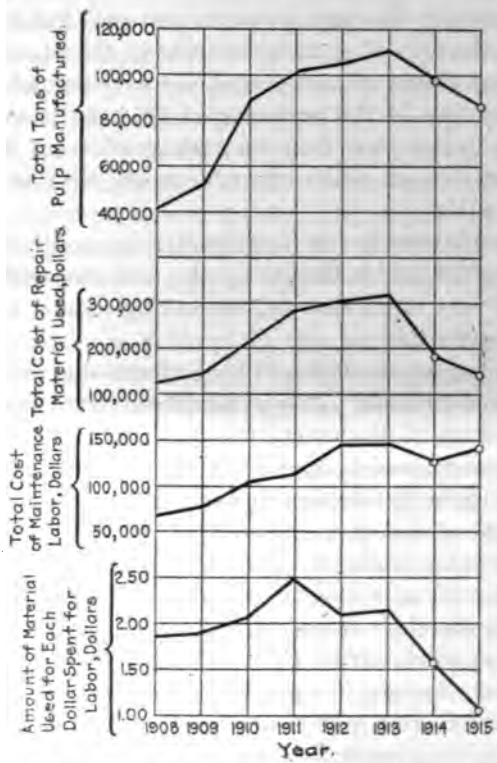

FIG. 3. SHOWING CONCRETE RESULTS OF COST SHEETS

obliged to get up a system of giving credit for material returned to the storehouse in order to help foremen keep down their job costs. This was in no sense a form of contract system, for all of our maintenance and construction men were paid by the hour and did not receive any more money for doing a job economically.

47 Fig. 3 shows the concrete results obtained by giving the cost sheets to the department heads and job costs to the maintenance

foremen. It will be noted there was a rapid increase in production from 1908 to 1913, also a rise in repair material used as well as an increase in the cost of maintenance labor. The fourth curve, showing the amount of material used for each dollar spent for maintenance labor, is more or less a resultant of the other two. The gradual rise from 1908 to 1911 in this curve was due to the increased material-consuming power of the maintenance men because of the introduction of labor-saving devices, such as pneumatic and electric portable tools. There was a drop in this figures in 1912 and 1913 but we were unable to get a real thought of economy started in the plant until the departmental cost sheets and job-cost sheets were started. These were put into effect first in the beginning of 1914 and there was an immediate drop in the curve from an average of about $2.15 worth of material spent for each dollar spent for labor, down to $1.55 in 1914 and $1.05 in 1915.

48 That this drop is due to the greater economy and thought in the use of materials is indicated by the fact that our maintenance crew was not very much reduced, the saving coming almost entirely in the use of materials.

49 The drop in production in 1914–15 was due to war conditions which were unavoidable. It is a significant fact, however, that in spite of this drop in production the maintenance material cost per ton of pulp was reduced to approximately half the amount under the conditions of higher production during the two preceding years.

50 In none of this work did we pay bonuses to a superintendent, department head or workman; our salaries and wages were high, but payments were all on a monthly, weekly, or hourly basis. The increased effort therefore came entirely from a desire within the individual to be productive. Of course this sort of creative effort produced great changes in operating conditions; we increased our yearly production from 42,000 tons to 111,000 tons without adding to the number of digesters for cooking the pulp, or wet machines for handling the finished product and we changed our quality from the poorest to the very best.

51 Due to the intelligent suggestion which came from our men all over the plant we were able to make very radical changes in the manufacturing processes. Entirely new methods of preparing our wood, making acid, bleaching, etc., were created, all of which we paid for out of the earnings.

52 I maintain that this was all the result of the freedom our men were experiencing because they were working in an environment

which stimulated thinking. They had ample opportunity constantly to increase their knowledge of the underlying natural laws of the process, and were therefore able to realize the joy which comes from a conscious mastery of their part of the process.

53 This freedom to express one's individuality in constructive work according to law, is the only real freedom, for freedom unrestrained by a consciousness of the universality of natural law leads to anarchy.

54 We should never lose sight of the fact that the degree of conscious self-expression which the workman can attain is in direct proportion to the ability of the organization to measure, for his benefit, the impress of his personality upon it. The most democratic industrial plant, therefore, is the one which permits the fullest possible amount of individual freedom to each member, irrespective of his position and at the same time is so sensitively adjusted that it reflects immediately the effects of his actions. If his actions result in injury to others he will see that as a part of the whole he, himself, must also suffer.

55 I have made no attempt in this paper to touch upon our method of arriving at the proper financial compensation as this is beyond the scope of the subject assigned to me. I feel that I should state, however, that in our mills in Canada, where the same scientific recording of operations is being developed, our wage rates are adjusted each spring after careful discussion with the representatives of our local labor organizations. This has proved to be a very just and satisfactory method, for the rates thus determined are really a consensus of opinion of both employer and employee and once the wage question is disposed of, all are free to devote their energies to the intelligent solution of manufacturing problems. Constant agitation of the question of financial renumeration only detracts from the work, and our experience has invariably been that there will be plenty of incentive to productive effort if the working environment is such that the workmen can express himself as an intelligent human being.

56 Man is not an animal, but a free, self-determining mental center of consciousness whose reason for existence is that the universal life can deal with a particular situation in time and space and, by this means, be enabled to evolve a material universe organized to express the one great individual life of which we are all a part.

57 In conclusion, let me say that I am well aware that to some of you this may seem like pure philosophical speculation far removed from the practical affairs of every-day life. I have said nothing, how-

ever, that I cannot back up by any number of additional illustrations, and my hope is that the examples given will stimulate others to make similar investigations, so that we can fulfill our mission in this country by evolving an industrial philosophy which will have for its ultimate aim the continuous unfoldment of the latent powers in man.

DISCUSSION

WALTER N. POLAKOV, who opened the discussion, said that the impression should not be gained that financial incentives are not important or even superfluous as long as non-financial incentives are at work. To illustrate his point he showed on the screen three charts dealing with fuel losses in a power plant. In the first chart, with neither financial nor non-financial incentives at work, the loss amounted to over 30 per cent. In the second, with non-financial incentives only, the loss had been reduced to 17 per cent, while in the third, with both financial and non-financial incentives, the preventable losses had been wiped out. The type of chart employed by Mr. Polakov is that shown in Fig. 2, page 718, *ante*.

W. E. PULIS, who followed Mr. Polakov, showed two slides dealing with the increase of production in a shop brought about by the introduction of financial incentives.

IRVING A. BERNDT [1] wrote that he was particularly impressed and in accord with what Mr. Wolf had said concerning the necessity of providing workers with environments which attract, and providing incentives inherent in the nature of the work itself. This was fundamental and basic. Were he to add any thought to this, it would be that the responsibility for this lay with the individual employer, manager and executive and should under no circumstances be passed on to society or to the worker himself. To show how large the non-financial incentive bulked in the production problem, Mr. Berndt enumerated twenty-four factors and ten methods which influence industrial relations, of which but two factors and one method had to do with monetary reward.

Being at one time confronted with the problem of reducing supplies taken from storerooms in a large plant — supplies used for maintenance and repair — Mr. Berndt found it possible to secure

[1] Care of C. E. Knoeppel & Co., 6 East 39th St., New York City.

interest among the men calling for them by placing at the storeroom window a list of current prices and a weekly bulletin telling how much the supplies used by each man or group had cost, comparisons being given. The two simple records stimulated interest and the desired result was secured. He had never found a foreman who was unresponsive to confidence placed in him by showing him records of costs, performances and even profits. He would not consider a monetary incentive properly applied unless it included a plan for keeping each man advised of current progress and also giving him a written statement of results.

HENRY L. GANTT said that the paper was an important contribution because it emphasized democracy in industry, and also that there could be no democracy in industry unless there was common knowledge of what was going on. Mr. Wolf had obtained remarkable results by letting every man know what he was doing and what was expected of him. The discussions of Messrs. Polakov and Pulis had indicated what could be accomplished when it was known exactly what men should do and when they were shown how to do it and paid a premium for doing it.

To know in advance how much each man should do of his various tasks, to know afterward how much he did do and to find the reasons why more had not been done, was not very easy, but it could be done in most cases. In many shops, however, it was not known how long it should take to perform the various operations or even the sequence in which they should be performed. He had found that incomparably better results were obtained by helping the slow and incompetent men to learn rather than by speeding up the man who was already fairly efficient.

In settling the problems confronting the employer and employee each concern was going to lay a foundation for harmonious coöperation by learning more about the conditions in its own shop and what there was that was hampering its workmen.

RICHARD A. FEISS thought that there was danger of interpreting Mr. Wolf's paper as a condemnation of financial incentives. Both financial and non-financial incentives had their place and must be taken into consideration. There were no cure-alls in industry, and failures in the application of so-called efficiency methods had grown out of a loss of perspective. The object, after all, was to obtain the best possible result from the human element in industry, and that

involved a psychological question. The problem of employment would be solved only by maintaining a broader vision, by remembering that the human being is a human being and must be studied from all points of view and under varying conditions. Mr. Wolf's paper had called attention to but a single element in management and it, with all the other elements in a given case, must be taken in consideration, remembering that man was a complex psychological as well as physical being.

A. L. De Leeuw said that the lasting growth of labor could only be caused by making labor develop from the inside out. The effort must be made by the laboring man, and not by the employer. The employer had only helped labor in general, but had not caused it to grow. Labor had taken the stand that it could grow only by antagonizing the employer, who, at one time, had held this same view regarding labor. Something should be done to make labor start developing itself in the proper direction. If labor had not already seen these facts, should not some one hold out the hand and invite labor to move in the right direction? Had not the time come when the engineer should get in touch with labor and invite it to discuss economic questions from a standpoint of pure and simple engineering, dropping all ideas of malice, and presenting the idea that a true bargain is one which benefits both parties? Should there not be a third party more or less disinterested, or, rather, interested in the welfare of both, who would hold out the hand to labor and invite it to develop itself, to make an organic growth from the inside outward? Would it not be well if some engineering society were to invite labor into its counsels and see that a proper organized effort was made to have it look at the question not only of its own development, but of the development of industry as a whole, and so bring labor to realize that no real benefits can ever come to it and be lasting unless similar benefits come to the industry as a whole?

Charles Whiting Baker pointed out the necessity of keeping up the volume of demand so that every workman might be employed, and that this could only be done by bringing down prices to where the people here and in Europe could buy. The industrial situation would have to be treated as a whole and if labor could be made to realize that raising wages by specific industries helped but little and that they would have to be reasonable in their demands so that prices could be sufficiently lowered, then it would be possible to get somewhere in the solution of this great problem confronting the country.

HUGO DIEMER said that to understand the economic principles underlying demand and consumption meant that the worker, the engineer and the general public must be educated. It was frequently stated that the engineer's viewpoint was narrow by reason of his not having given attention to the human phase of the situation. A course in Industrial Engineering given at The Pennsylvania State College for a number of years had been planned to remedy this in some measure. There students are given instruction in cost accounting and time study and devote considerable time to the study of labor, welfare and other industrial problems.

JOHN CLINTON PARKER said that the $30 a month the soldier in the war had received was certainly no financial incentive to him. He would define the non-financial incentive as being the same as that which prompted those who competed in sports or strove otherwise to win an honor or prize — that which impelled them to creditable performance.

FRANK B. GILBRETH spoke of the changed conditions confronting industry with the close of the war. Where a soldier was returning to his former job, held by some one whom he considered his inferior as a mechanic, he found that more output had been accomplished than he had been accustomed to do, and that greater productive effort was to be required of him in the future. So true was this in Europe that it had resulted in the elimination of practically all restrictions upon the size of individual outputs. The realization had now come that the financial success of a country depends upon the size of output per individual worker. Engineers and economists had known this fact for a long time, but many workers had not. They had held an honest belief that restricted output was the one thing which assured a job for every man. They were not going to believe this any more because the labor leader now knew that it was not true. Further, the worker henceforth would not only release all limitations upon output but would use his craft knowledge and skill to increase output. The workingmen's committee had been operating in a number of places as yet unannounced and with remarkable results. They were not interfering with the management in obtaining intensive outputs but were working on such things as the regulation of heating and ventilating, reduction of labor turnover, the selection and placement of the right man for the right place, fatigue elimination, education and corporation schools, and in some of the more advanced instances in

the motion-study laboratories for determining the One Best Way to do work.

While non-financial incentives that would cause the workers and employers to coöperate should be fostered, it must be ever borne in mind that the financial incentive is the cause of *maintenance* and *permanency* of coöperation and it should be large enough by itself alone to maintain the state of hearty coöperation through and past the reign of the malefactor.

ARTHUR C. JACKSON drew attention to the law that investment is entitled to an income. This investment might be in any of the following forms — cash, invention, accumulated earnings, or the results of the continued services of an employee. There should be a standard way of measuring all of these investments and it is the duty of the engineer to solve the problems of the fair division of the profits resulting from these investments. Wealth is not alone measured in money, but in the end in production. This country must continue to be an exporting nation and also an importing nation if it is to maintain its position among the countries of the world. We can only maintain a wage scale above that of our competitors by the proportion that our production exceeds the production of our competitors, either in quantity or quality; and this can best be done by the careful development of true coöperation by employee and employer. This coöperation could best be obtained, in his opinion, by the worker's being allowed a share in the management and in the profits.

OBERLIN SMITH, commenting on the law forbidding the use of stop watches and time studies in Government arsenals and navy yards, said that while congressmen and labor leaders were in the main well meaning and patriotic men, they nevertheless needed to be taught the true nature of scientific management, as their actions showed they did not understand it. Whether the combined engineering societies could do anything in the matter was a question to consider. Hence the desirability of electing men of the engineering fraternity to both houses of Congress, which important bodies are now almost entirely lacking such a personnel.

ARTHUR L. WILLISTON felt that the interest stimulated in an employee by teaching him how to perform his job properly would begin to lag after the attainment of the desired degree of perfection became an old story. He considered that the employer should have

a new and greater lesson to teach as the simpler ones were mastered, looking upon his workmen as progressing from stage to stage in his industry as students progress in college from one class to another.

SPENCER MILLER said it would seem that the author had contradicted himself in stating that men were rewarded by promotion and that the incentives were at the same time non-financial. He was very certain that there would be no conflict between capital and labor provided those involved comprehended that whatever stood for the idea of might would be defeated because public opinion would be arrayed against it. Public opinion in America was thoroughly united for righteousness, and if that could be finally kept in mind along with the fact that every human being would respond to it, then there would be no difficulties and the period of reconstruction would be passed through without strife. He proposed a vote of thanks from the Society to Mr. Wolf for having brought out so clearly in his paper the growing amity between capital and labor, which was unanimously adopted.

ROBERT L. SACKETT spoke of the increasing movement toward offering opportunities for instruction to the employee. This, he thought, was a form of non-financial incentive in spite of the fact that improvement on the worker's part would probably lead to increased compensation. In Pennsylvania alone nearly 5000 men had received instruction during the previous year in regularly organized classes, and in over 50 per cent of the cases the students met in the industrial establishments where they were employed. Aside from its value from the educational standpoint, this movement was finely effective in bringing employer and employee into closer sympathy. There was a real growth of appreciation in technical schools of the desirability of giving instruction in the humanistic side of engineering, and quite a number already included such instruction in their curricula.

THE AUTHOR in his closure, said that in his plants there was little consciousness of antagonism between employer and employee — all were fellow-workmen. He had secured the spirit of coöperation with his employees by appealing to their intelligence and sense of justice, adjusting their wages by conferences, etc. The men were promoted throughout the plant in much the same way that men progress through an educational institution. In his opinion there would never be any trouble with labor if the employer went to labor in a frank spirit of

open coöperation. Moreover, he believed labor leaders were beginning to realize that the workman must stop focusing his entire attention upon the distribution of wealth and focus it mainly upon the production of wealth, and that then the desired compensation must inevitably follow.

In reply to Mr. Polakov, he said that the reason his non-financial-incentive records did not show as great a saving as when a bonus was attached was because the plan of giving the men the record of their accomplishment without the bonus attached to it had not been properly tried out. Without deprecating bonuses entirely, he was of the opinion that they should be carefully considered. Men (both union and non-union) had said to him, "We don't like to be bribed to do a good job. We would like to have the privilege of doing a good job without being baited to do it."

Referring to Mr. Miller's comments, he said that he by no means deprecated the value of financial incentives; nevertheless, men did not do their best work for money. It was the record, the accomplishment of the man that counted, and it was fundamentally self-expression that the man wanted. The financial reward was bound to follow, and the employer who gave a man a chance to use his brain power and did not give him the financial compensation that went with it, was doomed to failure.

Regarding the disposition of the saving due to the improved efforts of employees, he was of the opinion that the money should be divided in proportion to actual earnings, that the men should be part owners of the industries. It had been because workers had not worked intelligently that employers had been able to deprive them of this division of profit. The employer had used his brain to exploit the employee; and the employee had countered by organizing his against the employer. That employee must be encouraged to use his brain for productive work. Then he would see to it as his mental capacity increased that proper reward followed.

No. 1674

NAVAL AND MILITARY PROGRESS

THE ACHIEVEMENTS OF NAVAL ENGINEERING IN THE WAR

By Lieut.-Com. William L. Cathcart,[1] U.S.N.R.F.
Member of the Society

WHILE the defeat of the Central Powers was due primarily to the early strength and continuous growth of the British Fleet, said Commander Cathcart, the American Navy had no inconsiderable part in the decisive work of the war's last year. It convoyed across 3000 miles of sea more than a third of that American Army of two million men which gave preponderating military strength in France — an achievement for rapidity of execution and the distance covered without parallel in the history of navies. During the last three months of the war, for every minute of the day and night, seven American soldiers, their equipment, and the maintenance for them, arrived in France.

From the very day of America's entry into the war the Navy grew by leaps and bounds until it became 600,000 men strong and operated about 2000 armed vessels and transports. On September 1 there were in European waters a total of about 275 ships carrying about 57,000 officers and men under command of Vice-Admiral Sims. The aggregate horsepower of these vessels was about 6,500,000, or thirteen times that of our fleet during the Spanish-American War.

The almost incredibly rapid repair of the German merchant vessels lying in our ports and seized by our Government when we entered the war, makes one of the most striking and dramatic stories in the history of naval engineering.

[1] Bureau of Steam Engineering, Navy Department.

Brief outline of an address delivered at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers. The address was printed substantially in full in Mechanical Engineering, January 1919, p. 18.

There were, in all, 103 of these German ships seized by our Government. Of this number about fifty were turned over to the Navy by the Shipping Board for repairs. The chief problem was the repair of the broken engine cylinders, some of which were more than 9 ft. in diameter. The Bureau estimated that — with such facilities as were available for this heavy work — it would take at least eighteen months to replace the damaged cylinders by new ones. Resort was therefore had to electric and oxy-acetylene welding, and after five months of strenuous work the ships were made ready for service.

These fifty ships were in service transporting troops for about a year before hostilities ended, which is approximately the time saved by using welding methods in the repair work. Twenty of these vessels can carry about 70,000 troops in one trip, and ten round trips a year is a conservative estimate of their performance. So it may be justly claimed that the rapidity of these repairs had a marked effect on the early end of the fighting in France.

Commander Cathcart's remarks were largely confined to details of the important work done by the various divisions of the Bureau of Steam Engineering — Design, Electrical, Repairs, Radio Telegraphy, Inspection, Supply, Fuel and Personnel, Aeronautics and Logs and Records, — and in his elaboration of this, among other things he gave interesting particulars regarding the use of the electric drive for battleships, the development of radio telegraphic and telephonic apparatus for communicating with aircraft, the immense amount of work carried on at the New York Navy Yard, the activities of the Naval Experiment Station at Annapolis and the valuable results obtained in the fuel-oil testing plant at the Philadelphia Navy Yard.

LONG-RANGE HEAVY NAVY GUNS WITH RAILWAY MOUNT

By Lieut.-Com. D. C. Buell,[1] U.S.N.R.F.
Non-Member

OWING to a change in the characteristics of certain battle cruisers, a number of 14-in. 50-caliber guns, originally built for hese ships, became available during November 1917 for other ervice.

It was felt that if these guns could be placed upon railroad ıountings they would prove a valuable adjunct to our artillery ɔrces, since they throw a 1400-lb. projectile at a muzzle velocity f 2800 ft. per sec., giving, at high elevations, an effective range of early 30 miles. They throw a heavier projectile with greater ccuracy and to a greater distance than any gun previously placed n mobile shore mounts.

But little preliminary discussion was necessary before the plan to ıse these guns in a naval railway battery was approved, and on Decem- ɔer 26, 1917, the Navy Bureau of Ordnance instructed the Naval Gun Factory at Washington to prepare plans and specifications for he project. These called for five 14-in. railway gun mounts, six ocomotives, and six complete trains of cars — 75 cars in all.

The last of the mounts was finished and delivered on May 25, ınd practically all of the cars and special equipment delivered for hipment by June 1 — hardly 100 days from the time bids were ɔpened, and only 155 days from the time the project was first onsidered.

A little later the Navy Bureau of Ordnance was requested by the Ordnance Department of the Army to build another lot of identical nounts. Work on these was pushed, and they were completed hortly after the middle of September, but it is to be regretted hat conditions were such that these mounts were not shipped to France in time to be erected and put into active service.

[1] Bureau of Ordnance, Washington, D. C.

Brief abstract of an illustrated lecture delivered at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers. The omplete text, together with a selection of the views shown, was published in Mechanical Engineering, January 1919, p. 25.

Shipments began on June 20, and on August 11 the first gun train was completed, leaving St. Nazaire six days later for the front and being fired against the Germans on September 5, less than 250 days from the inception of the project.

It was suggested by the French that if a similar type of mount could be devised for use where it was desired to bring the gun into action quickly, it would obviate the only possible objectionable feature of the first mount. It is interesting to know that the Navy Bureau of Ordnance, anticipating this requirement, had already designed and was building another battery of 14-in. mounts before the armistice was signed.

The guns complete each weigh about 550,000 lb. The shells weigh nearly 1500 lb. each and the powder charge for a shell 484 lb. The truck axles were designed to withstand a maximum axle load of 63,000 lb. The kinetic energy of the gun is about 4,000,000 ft-lb., which is absorbed through a hydraulic brake in the recoil of 44 in. in the slide, and when firing on the rails the movement to the rear along the tracks is about 26 ft. When firing from a pit the load is transmitted to foundation members in the form of a heavy grillage construction of castings and structural-steel shapes, the load being limited to about 4 tons per sq. ft.

RAILWAY ARTILLERY

By Colonel James B. Dillard,[1] U.S.A.
Non-Member

CONTRARY to general belief, railway artillery, according to Colonel Dillard, is not a recent development of ordnance. In 1863 a 13-in. mortar mounted on a flat car was used by the Union Army against the defenses of Richmond, and both the British and Boer forces in the South African war utilized naval or coast-defense guns on railway cars.

The types of cannon mounted on railway cars by the American Army are the same as those used in field and seacoast artillery, and

[1] Engineering Division, Ordnance Department, Washington, D. C.

Brief abstract of an illustrated lecture delivered at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers. The complete text, together with a selection of the views shown, was published in Mechanical Engineering, January, 1919, p. 44.

ıclude 12-in. mortars 9 to 12 calibers (diameters) long; 16-in. owitzers 15 to 20 calibers long, and 8- to 14-in. guns which vary in ngth from 30 to 50 or more calibers.

In the present war railway artillery was used for the following inds of fire: (*a*) Howitzer and mortar fire for the destruction of ıilway centers, depots, bridges, etc.; (*b*) long-range gun fire of ıterdiction for the destruction and interruption of traffic; (*c*) coun-ɜr battery work with 8-in. guns; and (*d*) reprisal bombardment.

The two main problems in the design of railway mounts are ·ansportation and provision for stresses due to gun firing. To andle mounts weighing 600,000 lb. and upward a system of trucks ıust be utilized that combines perfect equalization of loads and exibility. The condition of road beds in France limits all axle ›ads to not over 17 metric tons.

With guns up to 8 in. and howitzers up to 12 in. the limitations › design set by the railway clearances are slight, but in the case of owitzers of 16-in. and up, and with guns 12 in. and up, it was found ecessary to modify the design in one of several ways so that suffi-ient elevation for firing could be secured.

American types of railway artillery include: 7-in. 45-caliber uns mounted on barbette carriages; the 1918 model 8-in. gun, sing the same barbette carriage as the 7-in. gun; 12-in. mortars; ıe 12-in. 50-caliber gun with sliding mount, 105 ft. long over all, ·eighing 575,000 lb. and having a range of 30 miles; the 16-in. owitzer — the very latest type of railway artillery; and 14-in ;avy gun railway mount (see p. 949).

All railway artillery operates in batteries made up of four gun ıounts with their auxiliary cars, including ammunition, firing-ɔntrol, and supply cars. The ammunition car is a steel car pro-ided with a trolley I-beam and hoist for handling the ammuni-on, this being stored in racks. The fire-control car is a standard 0-ton box car with windows and is used as an office by the battery ɔmmander. The supply car is a standard 30-ton flat car on which ; carried auxiliary equipment and supplies.

The present state of the art of artillery design is such that guns .nd howitzers having a range of 22,000 meters or more are of such veight and exert such forces due to the firing of the gun that they nust be mounted either on fixed carriages or on railway cars. How-·ver, in the immediate future it is evident that guns mounted upon ·elf-propelled caterpillars will appear, and probably within the next ·ew years railway artillery will be limited to guns of 10 in. caliber

and up, and howitzers of 16 in. caliber and up. Caterpillar treads have been applied successfully to 7.5-in. guns and 8-in. howitzers and the next step will be their substitution for the railroad trucks in mounts such as the 8-in. gun and 12-in. mortar.

In the course of his remarks Colonel Dillard gave particulars of developments in railway artillery abroad, as well as details of the U. S. 8-in. gun and 12-in. mortar barbette carriages, and elaborated on the problems of design indicated in the foregoing paragraphs

No. 1675

RECOVERY OF GASOLINE FROM CASING-HEAD AND NATURAL GAS

By Paul Diserens, Cincinnati, Ohio

Member of the Society

In this paper the author describes in detail two methods of recovering casing-head gasoline, or that passing off in the form of vapor with natural gas from oil wells where both oil and gas are found in the same field. It is stated that the value of the recoverable gasoline in the gas is often as much as 20 per cent of the value of the oil produced.

In the first method the vapor-laden gas is alternately compressed and cooled, causing the gasoline to be thrown down as a condensate. In the second, used when the gasoline content is small, the gas is forced into intimate contact with a mineral oil that absorbs the gasoline vapor and the gasoline is later recovered from the oil by distillation. A combined absorption and compression method is also proposed.

CASING-HEAD gasoline is gasoline which passes off in the form of vapor with natural gas accompanying the flow of an oil well, where oil and gas are found in the same field. In many localities this gas is wasted because of the difficulty of handling it, or because no market exists for its sale, due to its relatively small volume. Often, however, the recoverable gasoline in the gas is worth as much as 20 per cent of the oil produced.

2 The practice of pumping casing-head gas to develop a vacuum on the well and thus to stimulate the flow of oil is, at this time, rapidly increasing and it is where this is done that plants for the recovery of casing-head gasoline are most profitable. In some fields, particularly California and Wyoming, gas is handled which comes directly from the wells under rock pressure or where the gas comes directly from gas wells. Such gas, however, yields relatively small quantities of gasoline.

3 The process most used in the recovery of casing-head gasoline is a physical one and involves only the alternate compression and cooling of the gas. As already stated, it will be understood that

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gasoline in the form of vapor constitutes part of the gas as it comes from the well or casing head. If the gas were saturated, gasoline would be immediately precipitated when compressed, provided it could be kept at a constant temperature, but since the heat of compression increases its temperature, the gasoline is still retained as vapor. When it is cooled, however, gasoline is thrown down in the form of condensate, and if the gas is cooled to its original temperature the gasoline still retained in it as vapor will only be in the proportion of its initial and final volume, or very approximately so. Since there are always present a great number of condensable fractions, each a different hydrocarbon of the paraffin series, the precipitate of each depends upon the partial pressure of each.

TABLE 1 VAPOR PRESSURES AND CORRESPONDING TEMPERATURES AT WHICH CERTAIN HYDROCARBONS WILL CONDENSE

Temperature, Deg. Fahr.	Vapor Pressure, Lb. per Sq. In.				
	Propane, C_3H_8	Butane, C_4H_{10}	Pentane, C_5H_{12}	Hexane, C_6H_{14}	Heptane, C_7H_{16}
32	72.5	15.9	3.5	0.9	0.2
40	84.6	19.9	4.4	1.0	0.3
50	100.7	24.1	5.4	1.4	0.4
60	115.4	30.0	6.8	2.0	0.5
70	130.1	36.7	8.2	2.5	0.7
80	147.2	44.1	9.9	2.9	0.9
90	165.0	53.2	11.9	3.2	1.1

4 The vapor pressures at which some of the hydrocarbons of the paraffin series constituting casing-head gas will condense for various temperatures are shown in Table 1. It is never practic[illegible] to determine exactly which of these hydrocarbons occur in th[illegible] particular casing-head gas to be handled, or in what proportions the[illegible] are found. It is not possible, therefore, to predict what total pressur[illegible] it will be best to carry. Generally, however, it is found advisable t[illegible] carry not less than 250 lb. and it seldom is profitable to carry mor[illegible] than 300 lb.

5 The application of the principle as briefly stated requires th[illegible] installation of a two-stage gas compressor with suitable intercooler and aftercooler. Vacuum pumps for bringing the gas from the wells t[illegible] the plant are also required. The intercooler and aftercooler are o[illegible] the open-coil type, and assuming that the surface available is larg[illegible] the efficiency attainable depends upon the temperature of the coolin[illegible]

water. It is of great importance, therefore, to make provision for an ample supply of water. For this purpose cooling towers are generally provided, since in most oil fields fresh water is obtainable only in limited quantities. With cooling towers, even of the best design, it is impossible to attain low temperature during the hot weather, which prevails during a large part of the year. As a means, therefore, of supplying additional cooling effect, an expander refrigerator is installed, the function of which is to reduce further the temperature of the gas itself after having passed through the cooling coils. It consists of a cross-compound expansion engine driving a gas compressor. The compressed gas coming from the aftercooler is used in this expansion engine, and because of the work done in its cylinders is expanded adiabatically, or, in other words, in such a manner as to reduce its temperature. The cold gas is then returned through double pipe coils where its refrigerating effect is utilized to further cool the compressed gas. The amount of refrigeration thus available is in direct proportion to the amount of work done in the compression cylinders driven by the expander, and is proportioned to the total number of expansions; that is, to the ratio between its initial and final pressure, provided, of course, the cylinders of the expander are properly proportioned. The expander produces this refrigeration without the expenditure of additional power, and the energy in the compressed gas, which otherwise would of necessity be wasted, is available for useful work in compressing additional gas used in the process.

6 Fig. 1 shows a plan and elevation of a gasoline plant. The gas is delivered by means of vacuum pumps, reference to which will be made later, to the tank *A*, where such gasoline as will be precipitated under ordinary conditions of temperature and atmospheric pressure or even slight vacuum is collected. The suction line to the low-pressure compressor is taken from the top of the so-called drip tank and leads to the low-pressure compressor *F*, where it is compressed to approximately 40 lb. gage pressure. It is then delivered to the cooling coils *C*. The condensation collected in these coils is drawn off through a trap and the dry gas returned to the suction of the high-pressure compressor *E*, where it is compressed to about 250 lb. and again passed through cooling coils *G*. The condensed gasoline in these coils is also removed by means of a trap and delivered to suitable storage tanks.

7 The original design of the plant as shown provided for the expansion of the compressed gas through a so-called Tripler tube *D*.

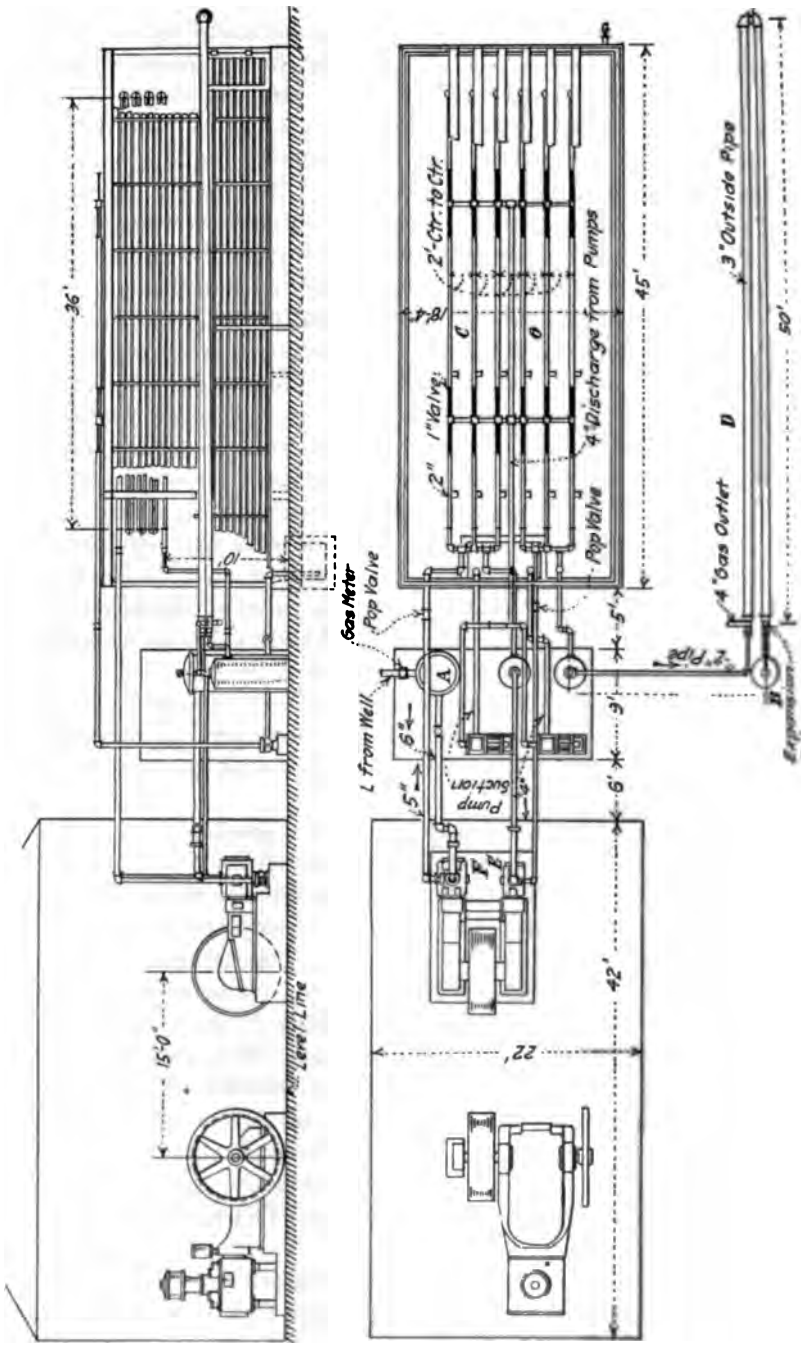

FIG. 1 PLAN AND ELEVATION OF COMPRESSION GASOLINE PLANT

This tube is similar in design to the ordinary double-pipe ammonia coil, the expanded gas passing around and surrounding the internal tube through which the compressed gas from the high stage is passed. The expansion of the high-pressure gas in this tube brings about a temperature reduction of the high-pressure gas and additional gasoline is precipitated. The impossibility of expanding gas adiabatically through a nozzle is well understood and for this reason it never has been possible to effect any great temperature reduction in this Tripler tube. As long as the expanded gas retains its high velocity the temperature is relatively low, but as soon as it comes to rest it rises very rapidly.

8 When the high-pressure gas expanded through the reducing valve in the Tripler tube contains appreciable quantities of gasoline in the form of mist rather than as a vapor, a considerable amount of cooling will be realized when this gasoline flashes into vapor as soon as the reduction in pressure takes place. This is explained, of course, by the fact that the heat of vaporization must come from the gas which carries the gasoline. A well-designed plant, however, should be equipped with accumulator tanks of sufficient size to separate practically all entrained liquid, and if this is done, the high-pressure gas will be practically dry when it reaches the expansion valve. Thus, if considerable refrigeration is actually brought about in the Tripler tube, it only signifies that the design of the plant is faulty. By the use of a Tripler tube some of this loss may be recovered in shape of refrigeration. The net result, however, will be a definite loss.

9 In order to bring about a greater temperature reduction through the expansion of this high-pressure gas, an expander compressor was installed. In the plant shown, a small single-stage expander was installed after the plant as just described was put in operation. The high-pressure gas after passing through the double pipe coil is admitted to the expansion cylinder of the expander compressor at approximately 250 lb. pressure and is exhausted against a back pressure of 15 to 20 lb. through the collecting tank *B*, and thence through the outside of the double pipe coil *D*, where it serves to cool the compressed gas within the inner tubes. The power developed in the expansion engine is used to compress additional gas, and this gas is delivered to the same intercooler and aftercooler, *C* and *G*, used by the main compressors.

10 The general piping arrangement in the plan as shown is rather crude, but is fairly representative of most plants which have

been in operation for two or three years. In some of the more modern plants a much more convenient and flexible arrangement will be found.

11 Even with a single-stage expander as installed in this plant, a very great increase in the yield of gasoline has resulted. The successful operation of this small single-stage expander was not easily accomplished. The collection of ice around the valves, together with the difficulty of lubricating them, made necessary numerous shutdowns. It was soon found, however, that by using glycerine in very small quantities as a lubricant and by applying this directly to the rubbing surfaces, the machine could be operated almost continuously. Whenever it was possible to reduce the temperature of the compressed gas approximately to the freezing point, all water vapor contained in it was frozen and thus removed before entering the expander. In very warm weather the amount of refrigeration available was not sufficient to bring about so great a temperature reduction, and at these times, after continued operation, the ice collecting in the exhaust ports and in the valve chest seriously interfered with its operation. It was found necessary to thaw out the expander at regular intervals, generally once in 24 hours. For this purpose a bypass pipe leading directly from the high-pressure compressor was used to bring high-pressure gas, before being cooled by the water coils, directly to the expansion cylinders. The temperature of this gas was sufficient to thaw out the ports in a very short time.

12 In order to overcome to a certain extent many of these difficulties in operation and in order to secure considerably lower temperatures, the expander compressor is now made as a cross-compound machine. It is possible, therefore, to carry the expansion much further and to reduce the temperature of the gas to a far greater extent.

13 No insulating material was used in this installation, and therefore the very low temperatures obtained were shown in a very spectacular manner. Frost and ice cover the cylinders and exhaust pipes to a depth of 6 to 10 in. The machine has expansion cylinders 10 in. and 18 in. in diameter with compression cylinders 17 in. and 8½ in. in diameter respectively; the stroke is 12 in. Indicator cards taken from the expansion cylinders (Fig. 2) show the performance of this machine. These cards are of particular interest. It will be seen that the expansion line follows very closely an equilateral hyperbola and therefore is not nearly so steep as the adiabatic, as might be expected. The explanation, however, is quite evident,

since the gas handled is not a dry gas but is in fact a mixture of dry gas and numerous condensable vapors of the various hydrocarbons referred to above. As soon as this mixture enters the cylinder and comes in contact with the very cold walls and ports, initial condensation takes place and as expansion proceeds, reëxpansion occurs exactly as in the case of the steam engine. The initial condensation, however, is very much greater and it is necessary to provide suitable drains in both cylinders to take care of the gasoline thus precipitated.

14 The initial temperature of the gas entering the high-pressure expansion cylinder in the plant in which these cards were taken,

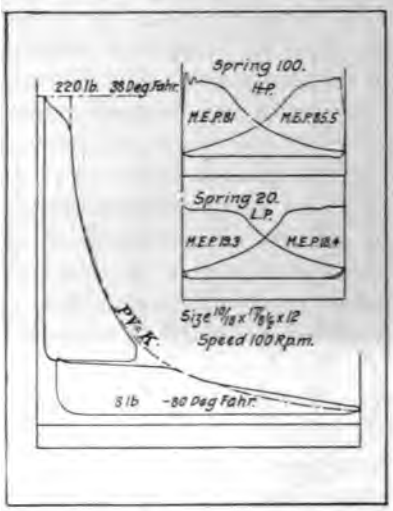

FIG. 2 TYPICAL INDICATOR CARDS FROM EXPANSION CYLINDERS OF GAS EXPANDER

averaged about 38 deg. fahr., while the temperature at the exhaust of the low-pressure expansion cylinder was 80 deg. below zero. The temperature of the high-pressure gas before entering the double pipe coils, through which the exhaust gas from the expander is taken, was 90 deg. If there had been no condensation in the expander cylinders and if the interchange of heat within the double pipe coils had been accomplished without loss by radiation, the final temperature of 80 deg. below zero should have been sufficient to reduce the temperature of the incoming gas to zero instead of 38 deg. above zero, since the compressed and expanded gas are of the same weight.

15 In order to bring about a more complete interchange of heat and in order to limit initial condensation, in one of the most recent

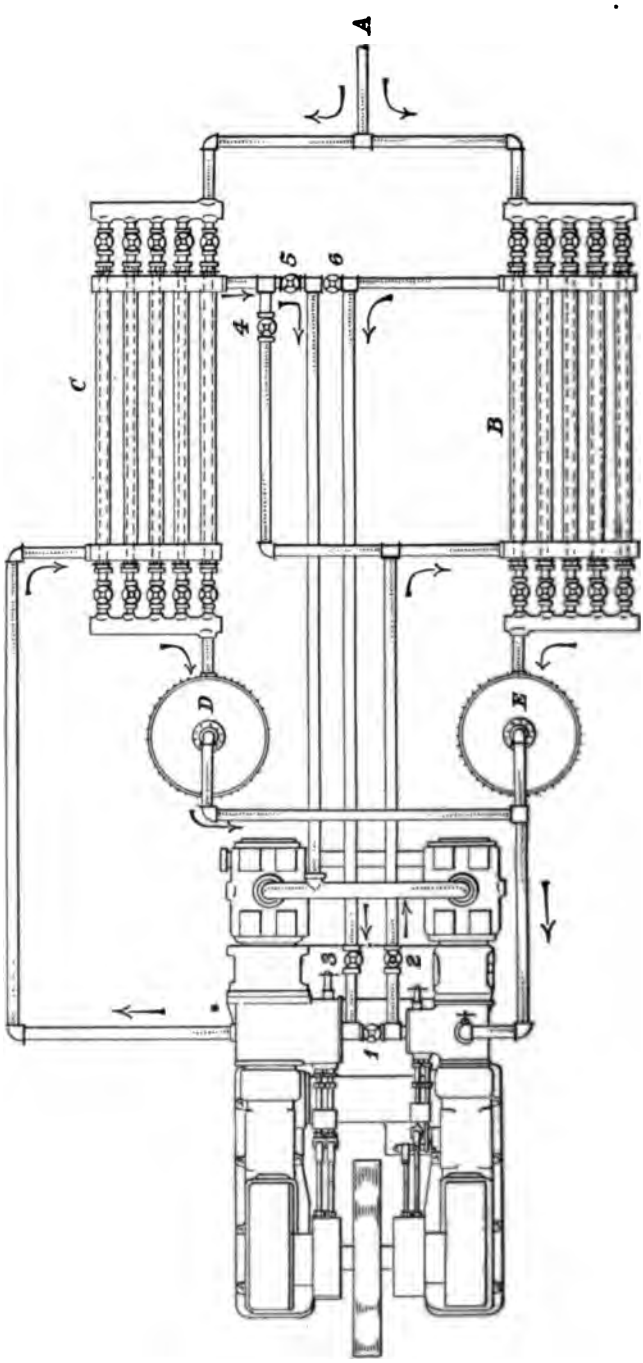

FIG. 3 HEAT EXCHANGER FOR TWO-STAGE EXPANDER

installations the two-stage expander was arranged so as to exhaust first from the high-pressure expander cylinder through a set of double pipe coils and then after further expansion in the low-pressure cylinder through another set of double pipe coils. By this means the range of temperature is, of course, greatly reduced and because of this fact there is considerably less initial condensation and, therefore, a greater interchange of heat. The general arrangement for such an installation is shown in Fig. 3.

16 The practical operation of these two-stage expanders is considerably simpler than that of the single-stage expanders originally installed. The reason is, of course, because of the considerably greater refrigerating effect obtained. In many plants it is easily possible to operate the expander continuously for indefinite periods, but in particularly warm climates and where the gas is very rich in condensable vapors, the temperatures even with a two-stage machine are not sufficiently low to prevent accumulation of ice within the cylinders. By using hot gas at regular intervals to thaw out the pipes, these plants can be operated very successfully.

17 Next to the expander the vacuum pump is, perhaps, the most interesting apparatus used in a gasoline plant. When the production of relatively old wells begins to fall off, it has been found that the flow of oil can be very materially increased by developing a vacuum in the casing. Until recently this was done by attaching a rather crude direct-acting pump directly to the rigging of the well. With a pump of this kind it is seldom possible to develop a vacuum of more than 10 in. to 12 in. of mercury. Competition between owners of adjoining leases to carry the highest possible vacuum, in order to get their full share of the oil, has recently brought about a demand for vacuum pumps of much greater efficiency, and so within the last few years a great number of high-speed, high-efficiency vacuum pumps driven by gas engines have been installed.

18 While there are now on the market two or three vacuum pumps of relatively high efficiency, the newest and perhaps the most novel in design is found in the Laidlaw feather-valve vacuum pump. Its construction and performance will therefore be of interest.

19 This vacuum pump depends for high efficiency upon close clearance and its distinguishing feature is found in the use of voluntary valves of the feather type. Each valve consists of a number of thin, flexible strips of spring steel, working on a flat seat and opening against a slotted guard. The ends of the valves never leave the valve seat, the opening being accomplished by continuous bending

of the valve strip itself. The valve, therefore, in closing, seats through gradual contact from the ends of the valve toward the center and not by direct impact. This makes it possible to give the valve a relatively high lift and consequently relatively large valve area. Because of the extreme flexibility of the valve strips used, even the very light pressures incident to vacuum-pump work are sufficient to hold the valve to the seat with extreme tightness.

20 A vacuum pump of this type can easily develop a vacuum on closed suction of 29½ in. of mercury, or, in other words, within ½ in. of the barometer. This of course determines the volumetric efficiency of the vacuum pump at any working vacuum, for assuming that the volumetric loss in a vacuum pump is directly proportional to the number of compressions under any working conditions, the volumetric loss will be the ratio of this number of compressions to that obtained with the pump working on a closed suction, since under this condition of operation the volumetric efficiency will be zero, in other words, when the volumetric loss exactly equals the capacity of the pump. With this assumption it is possible to express algebraically the actual capacity of any vacuum pump for any given working condition. For example, the actual capacity of a vacuum pump having a displacement of D cu. ft. per min. that will deliver Q cu. ft. of free gas per 24 hours, is expressed by the following formula: $Q = 1440\ D \times (C - V)/B$, where B is the barometric pressure, V the actual working vacuum and C the vacuum developed on closed suction. The relationship thus defined gives a very simple means of determining the size of pump required for any particular service, for it is only necessary to know the amount of gas available, the vacuum at which it is to be handled and the vacuum which the pump will develop with its suction closed.

21 In order to facilitate the choice of a pump for any particular service, the chart shown in Fig. 4 will be useful. This chart shows the capacity of vacuum pumps having any displacement ranging from 500 cu. ft. per min. to 10,000 cu. ft. per min. and working under any degree of vacuum up to 28½ in. of mercury, referred to a barometer reading of 29½ in. On this chart are shown three efficiency lines corresponding to pumps capable of maintaining ½, 1 and 1½ in. mercury absolute on a closed suction.

22 The use of this chart is illustrated by the following example. If it is required to select a pump capable of handling 500,000 cu. ft. of free gas per day at 21 in. of vacuum, proceed as follows: Select the horizontal line marked "21 inches" at the left of the diagram,

low this line in a horizontal direction to its intersection with the rved efficiency line marked "one-half inch." On the vertical e passing through this intersection, proceed vertically until the rizontal line marked 500,000 on the extreme right of the diagram is ıched. The diagonal line passing through this intersection repreıts the displacement in cubic feet per minute of the vacuum pump ıich will give the required service. It will be seen in the example ected that the vacuum pump must have a displacement of 1200 . ft. per min.

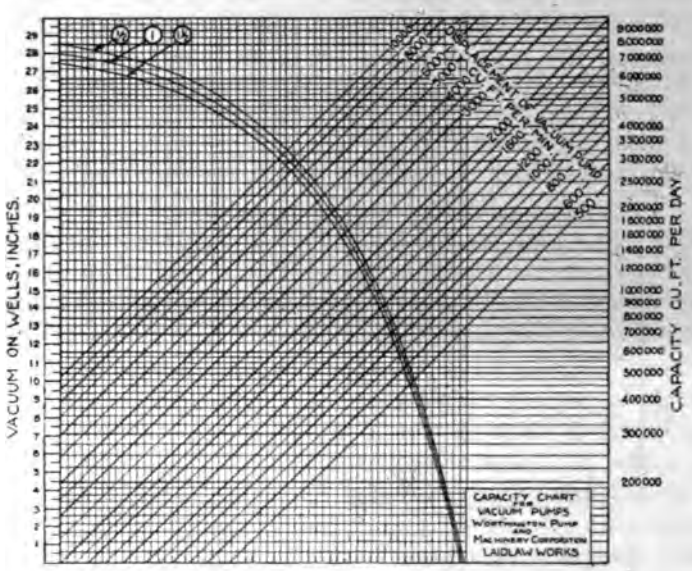

FIG. 4 CAPACITY CHART FOR VACUUM PUMPS

23 The results of a test on one of these vacuum pumps to demine its actual volumetric efficiency are shown in this diagram. e quantity of air handled was measured by means of a low-pressure fice, using Professor Durley's coefficients; the results are plotted volumetric efficiency for various working vacua. The heavy e shown in this diagram represents the volumetric efficiency calated from the chart already shown. The actual test results ncide with a fair degree of accuracy with those estimated from the ırt.

24 Another method of recovering gasoline from natural gas or ing-head gas is by what is known as the absorption process

This process is used primarily where the gas treated is lean, that is, when its gasoline content is small.

25 In the absorption process the wet gas, together with the absorbing oil (usually mineral seal or straw oil), is forced under pressure into the absorber where the two come into intimate contact, the proportions of gas and oil being so controlled that the oil, when leaving the absorber, will be approximately saturated with condensable vapor from the gas. On leaving the absorber the saturated oil is passed through suitable heat interchangers, where its temperature is raised by means of hot return oil from the still. The hot saturated oil is then led to the still, where additional heat is applied, and the gasoline driven off in the form of vapor. These

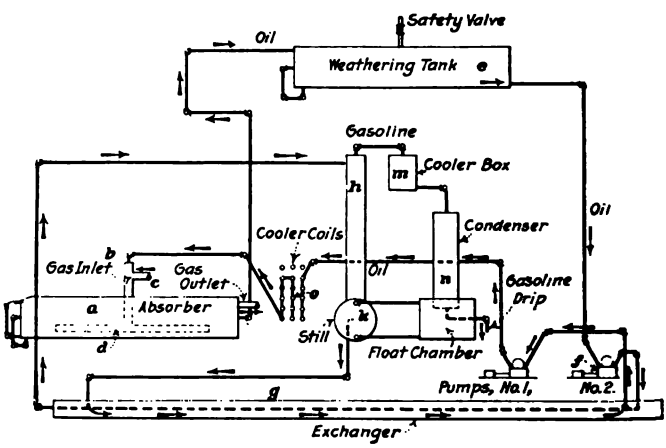

FIG. 5 GENERAL ARRANGEMENT OF SMALL GASOLINE ABSORPTION PLANT
(From Bulletin 120, Bureau of Mines)

gasoline vapors are condensed in water-cooled coils and delivered suitable blending and storage tanks. The residue-absorbing oil is then returned to the heat interchanger, where it gives up a great part of its heat to fresh saturated oil, as described above, after which it is passed through a cooler similar in design to the water cooler coils of the compression plant, where its temperature is reduced to the lowest possible point. After cooling the oil is returned directly to the absorber. It will be seen that the process is a continuous one, and that the absorbing oil is used over and over again.

26 Fig. 5 shows diagramatically the general arrangement of a small absorption plant. The natural gas, which is brought in from a pipe line under pressure, enters the absorbing tank at c and the

il enters at *b*. They pass into the T-pipe *d*, and the mixture passes om there through many small holes into the oil contained in the bsorber. The gas bubbles up through the oil and passes out of the bsorber as shown and returns to the pipe line.

27 The oil charged with gasoline passes first to the weathering ank *e*, where the lighter parts of the gasoline are released through ie safety valve. Next the oil enters the pump *f* and is pumped irough the heat exchanger *g* into the rock tower *h* of the steam still , where the gasoline is distilled from the oil with live steam. The ooler *m* separates the water (condensed steam) from the gasoline, 'hich is condensed in the condenser and flows out of the system at he gasoline drip.

28 The hot oil after having been freed of its gasoline is passed hrough the heat exchanger *g* and heats the oil passing to the still nd from No. 1 pump it is forced through the cooling coils *o*, on 'hich running water drops. The cooled oil then passes into the bsorber *a* to receive another charge of gasoline.

29 In the absorption method it will be seen that a very considrable amount of gas must be burned under boilers to generate ufficient steam to operate the steam stills. Since in nearly every istance absorption plants are installed as an adjunct to a gas-pumpig station used to supply gas for domestic service, the diversion of ny considerable amount of gas to operate boilers instead of pumping through the mains where it has a market value of probably 30 r 40 cents per 1000 cu. ft., operates to greatly reduce the profits to be erived from the gasoline plant. Any system, therefore, which will o away with the necessity of separating the gasoline from the aborbing oil by means of steam stills is greatly to be desired. While s yet no such plants have been installed, a very interesting solution f the problem has been proposed in a combination of the absorption nd compression processes. The plan contemplates the absorption f the gasoline in the usual way, as already described, and then itroducing the resulting blend of absorbing oil and gasoline into a losed vessel in which a high vacuum is maintained. The gasoline 'ill, of course, immediately volatilize, and may be removed by means f vacuum pumps, passed through cooling coils and condensed.

30 The general arrangement of such a plant is shown in Fig. 6. t will be seen that it consists of three elements, an evaporator, a acuum pump, and a bank of cooling coils with suitable accumulator ank. The saturated oil from the absorbers is pumped into the vaporator through spray nozzles which deliver it in a finely divided

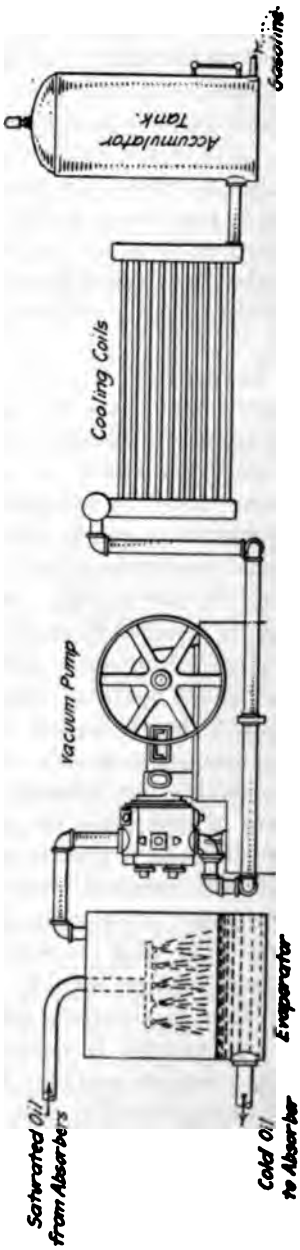

FIG. 6 COMBINED ABSORPTION AND COMPRESSION PLANT

mist. Because of its relatively low boiling point the gasoline must of course come from the absorbing liquid, and thus the process brings about a refrigerating effect and the oil itself is cooled. This is an item of extreme importance, since the oil upon its return to the absorbers will be at a temperature low enough to bring about most effective absorption. In the ordinary absorption plant the principal factor which limits its efficiency is this temperature, and great pains are always taken to keep it as low as possible. The vacuum pump serves not only to maintain the required vacuum within the evaporator, but also to remove the gasoline vapors. These are delivered to the cooling coils, which may be in every way similar to those used in the compression process.

No. 1676

SOME FACTORS IN FUEL ECONOMY IN BOILER PLANTS

By Robert H. Kuss, Chicago, Ill.
Member of the Society

According to the author's estimates, it should be easily possible to increase the combined boiler and furnace efficiency of stationary plants burning bituminous coal from 12 to 15 per cent above that ordinarily obtained. Conditions regarding character of fuel, design of furnace and grates, facilities for introducing air, draft, etc., are accordingly stated, compliance with which should substantially effect the savings mentioned in the case of a single boiler. The case of several boilers combined for service is also considered, and the author outlines a novel scheme of operation and points out the advantages it possesses over the ordinary method of running.

THE total bituminous coal production in the United States during 1917 was close to 542,000,000 tons, and in the same year 90,000,000 ton of anthracite were marketed. The uses to which the bituminous coal was put have been estimated as given in Table 1. Forty per cent of the anthracite production was consumed by locomotives, and the remainder mostly by domestic users.

2 It is easy to see from Table 1 that 60 per cent of the total coal production in the United States during 1917 was applied to non-productive uses: namely, 35 per cent for steam locomotives plus 25 per cent for household use; or, to put it more strikingly, while the railways hauled all of the coal output it took 35 per cent of the coal production to conduct the entire business of hauling. Although impossible to form a coal budget for 1918, competent authorities seem to agree that the production must be increased by not less than one hundred million tons of bituminous coal.

3 Much needless transporting of coal has been practiced, and therefore the Fuel Administration's order restraining coal shipments within areas of natural consumption was good judgment. The hardships follow owing to the necessity of using a grade or quality of coal in equipment designed for a more distant product. This of

Presented before the Detroit Section of The American Society of Mechanical Engineers, May 3, 1918.

course is particularly evident in the domestic field where West Virginia coal has been shipped in vast quantities to the larger population centers at a considerable distance.

4 With a fixed system for transporting coal and with added demands for its use, it is manifestly necessary to transport all coal possible during the summer months, thus compelling storage in vast quantities. The difficulties of storage, such as the likelihood of spontaneous combustion, are well understood and can be avoided.

5 While it is not possible to fix a definite figure or even range representing the ratio of heat absorption to that of possible heat evolution or, stated otherwise, the efficiency for the respective groups of manufacturing, locomotive and domestic use, it is nevertheless desirable to look into this phase of the matter. The average estimates which appear in Table 2 are accordingly submitted by the

TABLE 1 BITUMINOUS COAL CONSUMPTION IN THE UNITED STATES, 1917

Kind of Plant	Tons	Per Cent
Stationary steam	215,000,000	40
Railway locomotives	190,000,000	35
Households	135,000,000	25
	540,000,000	100

writer for what they are worth and have to do with the performance of the several groups applied to a year's period, all losses being charged.

6 Granting that all of these figures are merely speculative, they still show that the largest possibilities rest within the province of the duties naturally supervised by men such as ourselves. With respect to the large avoidable losses in burning domestic fuel, it must be borne in mind that even were the reclamation or saving of coal by more economical use larger than the estimates in Table 2 indicate, the difficulties attending a proper dissemination of knowledge to effect the possible economies are extreme.

7 Dealing with a single furnace the particular features needing consideration are:

a The character and physical condition of the coal
b The manner of introducing the coal into the furnace
c The shape, size and construction of the grate

d The shape and size of the chamber in which evolved gases burn

e The facilities for introducing air either through or above the fuel bed.

8 Any means which tend to cause the gases of combustion to be evolved or distilled uniformly are in the direction of complete combustion, and this is especially affected by the character of the coal and the method of introducing it. Manifestly, with a uniform gas distillation the cubical capacity of a furnace need not be as large as for variable distillation to obtain the same effect, for the determining factor in the complete distillation of fuel is sufficient air

TABLE 2 ESTIMATED PERCENTAGE EFFICIENCIES WHEN USING BITUMINOUS COAL

	Stationary Plants		Railway Locomotives	Domestic
	High-Pressure	Low-Pressure		
Poor practice	50	40	60	30
Fair practice	64	56	66	40
Good practice	72–74	62	70	50
Available practice	76	68	72	55
Available increase	12	14	9	15
Available savings, tons	25,800,000		17,100,000	20,250,000
Total tonnage saving on 1917 basis				63,150,000

adequately mixed with the evolved gases and maintained at a high temperature long enough to insure the completion of the combustion process before encountering relatively cool surfaces.

9 Air that does not enter into the actual combustion process is a source of loss whether the process is complete or not. Complete combustion does not argue economy, for the air admitted to bring it about may, and frequently does, exceed the amount required and be introduced in such places or in such ways as to offer itself as a vehicle for absorbing heat without assisting in its generation. Fundamentally, then, the items of importance are the rate and degree of uniformity of gas distillation. The usual failures in these particulars are due to the fact that the grate surfaces employed and air facilities provided are disproportionate to the steam demands, thus

resulting in improper fuel beds and making it extremely difficult to cause the furnace to function as stated. Such conditions result in oversupplying air in certain sections, undersupplying it in others and in failing both to mix the air and gases and maintain them at a high temperature within the capacity of the furnace.

10 Referring to a particular design and condition of equipment, it happens that boilers perform at about the same efficiencies throughout their ranges of duty. In other words, clean enclosed heating surface will absorb about the same percentage of heat without regard to the quantity supplied to it within the range commonly encountered in practice, say, up to 250 per cent of builders' rating. This does not mean that all boilers are equally good or equally good heat absorbers; it has to do with the proposition that for a given design or shape of heating surface it is not essential to be concerned with the amount of heat delivered to envelop it, for the proportion absorbed will be practically the same in any case. On the other hand, the conditions surrounding boilers do play a big part in the resulting efficiencies and divide themselves mainly into cleanliness of both sides of the heating surface and the condition of the enclosing structure or setting of the boiler.

11 Boiler and furnace efficiency depend on the manner in which draft facilities are provided and utilized. In connection with draft there are the following points to bear in mind:

a There must be provided a surplusage of draft intensity capable of being exerted at the fuel-bed end of the installation, so that momentarily greater steam demands may be met or temporary faults of fuel-bed construction overcome

b Good judgment demands that the chimney or fan shall not have its purposes partially defeated by tortuous, ill-shaped breechings or faulty passages through the settings

c Not only must the facilities for creating air movement through the fire be adequate, but the room delivering air to the system must have provision for the introduction of the volume of air needed for the combustion processes

d Causes which tend to reduce draft intensity, as by soot deposits and air infiltration, not only bring about losses of their own accord but tend to destroy the available elasticity of furnace operation, which is more serious

e Furnace draft should at all times be ample to overcome the resistance of the fuel bed

f The rate of failure of furnace parts is inseparably tied up with the ability of the draft forces to carry away the heated gases as rapidly as evolved.

12 When several boilers are combined for service, there is usually a wide choice given in selecting the number to be run. Assume an ordinary plant containing eight 400-hp. boilers equipped with stokers adapted to the fuel being supplied. Suppose the draft facilities are ample and the load variation between 2500 and 2800 hp., momentarily going as high as 3000 hp. By ample draft is meant sufficient to burn without serious furnace injury enough coal (or more) on each grate to generate 760 hp. or 90 per cent overload.

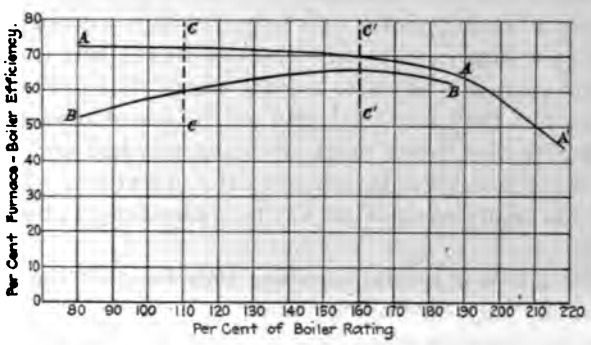

FIG. 1 EFFECT OF VARIOUS RATINGS OF THE BOILER ON COMBINED EFFICIENCY

AA Available efficiency.
BB Usual operating efficiency.
CC—C'C' Proposed range of operating units.
C'C' Proposed rate of operating units for normal loads.
AA' Drop in efficiency due to insufficient furnace capacity.

The ordinary way to run the plant would be to place six or seven boilers in service, keeping two or one down for general cleaning, and meet the load changes by altering damper positions, grate speeds, etc.

13 In Fig. 1 the line *AA* represents what may be termed the maximum combined efficiency over the range of operating rates. The mere fact that it is possible to attain these efficiencies at the different ratings does not secure their attainment. As a matter of fact, the lower the rate of operation the greater the opportunity for improper draft adjustments, poor fuel beds, uncleanliness and air leakages to go on unchecked and uncorrected. The effect is to obtain on the average a performance somewhat as represented in the

efficiency curve *BB*. This has the characteristic of rising to a maximum height between 150 and 160 per cent of boiler rating. The conclusion is that it is best to run the boiler at around 150 and 160 per cent for normal loads.

14 Applying this judgment to the problem, take 2650 b.hp. as the mean point of service demanded and divide by 640, the latter figure being the product of 400 and 1.60. Thus four boilers will ordinarily carry the load if means are taken to operate the units at this rating. Now, how shall the momentary loads beyond be handled? By bringing up one unit at a time to its maximum capacity as the load increases up to the 3000 hp. of the original problem. In a like manner, when the load decreases, first one unit is reduced to, say, 110 per cent of rating, and if that reduction is not enough, a second unit is taken in hand, and so on. In other words, here is an attempt to push the operating forces to a place where they dare not neglect their duties lest they lose their grip on the steam pressure. When it is considered that fewer units are being watched and less fuel is handled, the net result is favorable to the operatives. The scheme advanced has many advantages for its application, as borne out by experience.

15 The above is a mild case and thus far only the immediate benefits in the way of economy have been stated. The corollary benefits no less important are: less blowing down; less soot accumulation and less effort and steam for its removal; less brick maintenance per ton of coal burned; less coal loss at the closing periods of the operating day and at other slow-down periods; greater time for inspection, overhauling, cleaning and repairs; and less percentage loss due to unavoidable losses such as radiation.

16 The ability to apply this system to its logical and best conclusion depends upon whether the available draft is adequate. If deficient, thus not permitting the attainment of a curve such as *AA*, then the opportunity for effecting the larger efficiencies is excluded, but the principle is still applicable. If the furnace capacity is inadequate, thereby causing its efficiency to fall rapidly at the higher rates, then the limits through which the scheme can be successfully applied are correspondingly reduced. If the plant is hand-fired (or even stoker-fired) and has less units than that mentioned in the problem, perhaps the exclusion of one whole unit may be impracticable; in that case each grate size should be reduced. Naturally it is extremely important to know just what the possible performance of each boiler unit may be throughout its range of working; also,

vhat is expected of the plant as a whole in the way of steam lemands.

17 Few instruments are needed for an ordinary plant, but those nust be regularly used and the records reviewed and studied. Every ›oiler setting should have a draft gage or draft-gage system capable ›f instant or constant indication of boiler uptake and furnace drafts, ,nd there should be accurate water-measuring and coal-weighing ,pparatus. Each chief engineer of a plant of, say, 600 b.hp. should ›ossess a standard Orsat or gas-analyzing set and an indicating ›yrometer.

No. 1677

VALVES AND FITTINGS FOR HIGH HYDRAULIC PRESSURES

THEIR DESIGN AND MAINTENANCE IN OPERATION FOR PRESSURES OF FROM 1000 TO 8000 LB. PER SQ. IN.

By Wm. W. Gaylord, Torrington, Conn.
Junior Member of the Society

This paper suggests a method of figuring the strength of hydraulic pipe, valves and fittings based on the maximum-shear theory modified to conform to the results of the experiments of Cooke and Robertson published in "Engineering," December 15, 1911, and shows it applied to a system to use 7500 lb. per sq. in. working pressure. It describes the joints, fittings and valves used on this system, both those that proved satisfactory and those that failed in operation.

It also shows and describes a multiple cam-operated valve for use with a three-cylinder press, so arranged that a continued rotation of the valve-operating wheel in one direction operates the individual cylinders of the press through a complete cycle of operations, thus largely eliminating the personal equation of the operator. An auxiliary valve used to speed up the return stroke of the large cylinder of this press is also described.

The design of a system in which an accumulator is used is discussed and the special precautions required to avoid water hammer considered.

WITH the greater use of hydraulic machines of various sorts as the result of the large manufacture of munitions, a greater interest is to be expected in the design of valves and fittings for such machines. This paper gives the results of my experience and I have written it largely in the hope that others may be led to publish the results of theirs.

2 A few years ago when the problem was presented to me of designing a new hydraulic system for a working pressure of 5000 lb. per sq. in., with the probability that this would be increased to 7500 lb. per sq. in., I found there had been very little published on the design of valves and fittings for this pressure and that the designing formulæ given in standard handbooks were either incorrect or unsatisfactory. The formula most generally given was that of Lamé,

Presented at the Annual Meeting, December 1918, of The American Society of Mechanical Engineers.

based on the maximum-stress theory, which, while correct for cast iron, is not satisfactory for steel. Lanza, in his Applied Mechanics, gives a modification of the Grashof formula based on the maximum-strain theory, which I had used before with fair results for steel fittings on lower pressures. I had, however, noticed some unaccountable failures when applied to the pipe and fittings of a system using a working pressure of 4000 to 4500 lb. per sq. in.

3 While studying these failures my attention was called to the maximum-shear theory proposed by Guest, and this seemed to explain most of them. About this time the results of the experiments of Cook and Robertson were published in *Engineering*, (December 15, 1911), and after considerable study I became convinced that these offered the best basis for design.

4 The form in which they give the formula for fiber stress, based on the maximum-shear theory, is

$$\frac{P}{f} = \frac{K^2 - 1}{2K^2}$$

where P is the internal pressure in pounds per square inch, f the fiber stress, and K the ratio of external to internal diameter. This is the equivalent of the usual formula

$$f = P\frac{2}{1 - \frac{d_0^2}{d_1^2}},$$

where d_0 is the internal diameter and d_1 the external diameter, as can be seen by substituting $\frac{d_0}{d_1}$, for K; thus:

$$\frac{P}{f} = \frac{\frac{d_1^2}{d_0^2} - 1}{2\frac{d_1^2}{d_0^2}} = \frac{d_1^2 - d_0^2}{d_0^2} \times \frac{d_0^2}{2d_1^2} = \frac{d_1^2 - d_0^2}{2d_1^2}$$

whence

$$2Pd_1^2 = f(d_1^2 - d_0^2)$$

or

$$f = P\frac{2d_1^2}{d_1^2 - d_0^2} = P\frac{2}{1 - \frac{d_0^2}{d_1^2}}.$$

5 The results of their experiments show that if a factor of 1.2 were introduced the equation would more nearly represent the actual results, so the formula suggested by them becomes

$$\frac{P}{f} = 1.2\frac{K^2 - 1}{2K^2}.$$

6 This formula I transformed to give the thickness of cylinder wall t for cylinder of inside radius r by substituting $\frac{r+t}{r}$ for K; thus:

$$\frac{P}{f} = 1.2\frac{\left(\frac{r+t}{r}\right)^2 - 1}{2\left(\frac{r+t}{r}\right)^2}$$

$$= 0.6\frac{r^2 + 2rt + t^2 - r^2}{r^2} \times \frac{r^2}{r^2 + 2rt + t^2}$$

$$= 0.6\frac{2rt + t^2}{r^2 + 2rt + t^2}$$

or

$$Pr^2 + 2Prt + Pt^2 = 1.2frt + 0.6ft^2$$

Transposing,

$$0.6ft^2 - Pt^2 + 1.2frt - 2Prt = Pr^2$$

or

$$(0.6f - P)t^2 + 2(0.6f - P)rt = Pr^2$$

$$(t + r)^2 = \frac{Pr^2}{0.6f - P} + r^2$$

and

$$t = -r \pm \sqrt{\frac{Pr^2}{0.6f - P} + r^2}$$

which makes it much more convenient for general use.

7 From this formula it is apparent that a material having a working fiber stress of 12,500 lb. per sq. in. or less would not be safe, however thick the pipe wall. This, of course, eliminates bronze, cast iron and semi-steel as materials for making these fittings. After careful consideration of the materials available it was found that cold-drawn seamless steel pipe annealed to give 45,000 lb. per sq. in. elastic limit, and steel castings for fittings giving 30,000 to 35,000 lb. per sq. in. elastic limit, could be obtained, and it was decided to use these. As the system had no accumulator and therefore was not subjected to severe shocks, a working fiber stress of 0.6 of the elastic limit was used.

8 The largest pipe in the system was to take as a maximum the discharge of five pumps, each of 60 gal. per min. capacity, making a maximum flow of 300 gal. per min., but under usual working conditions only three pumps or 180 gal. would be used. In view of this

a maximum velocity of 20 ft. per sec. or a usual velocity of 12 ft. per sec. was allowed, which required a pipe of $2\frac{3}{4}$ in. inside diameter. From the above formula the thickness required for a pipe of $2\frac{3}{4}$ in. inside diameter is

$$t = -1.375 \pm \sqrt{\frac{7500 \times \overline{1.375}^2}{0.6 \times 27000 - 7500} + \overline{1.375}^2}$$

$$= -1.375 \pm \sqrt{\frac{14180}{8700} + 1.891} = -1.375 \pm 1.876$$

$$= 0.51 \text{ in.}$$

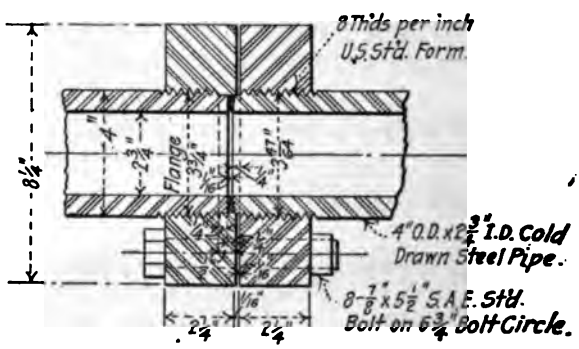

FIG. 1 TYPICAL FLANGED JOINT FOR 7500 LB. PER SQ. IN.

and for a fitting

$$t = -1.375 \pm \sqrt{\frac{7500 \times \overline{1.375}^2}{0.6 \times 19500 - 7500} + \overline{1.375}^2}$$

$$= -1.375 \pm \sqrt{\frac{14180}{4200} + 1.891}$$

$$= 0.925 \text{ in.}$$

9 A pipe having 4-in. outside and $2\frac{3}{4}$-in. inside diameters was chosen, as this was a commercial size and allowed the necessary thickness of metal for threading to use in a joint of the type shown in Fig. 1. The fittings were made with a 1-in. wall thickness, the tee shown in Fig. 2 being an example of the type used.

10 The bolting of the flange was figured by assuming that the full pressure was applied to the area of a circle of the outside diameter of the gasket. In the joint in Fig. 1 this would make a total load on the bolts of $1.875^2 \times 3.142 \times 7500 = 83{,}150$ lb., which would require eight $1\frac{3}{8}$-in. bolts if U. S. standard bolts were used, allowing a working fiber stress of 10,000 lb. per sq. in. This would

have taken a flange about 11 in. in diameter and would have made the piping very hard to install in the limited space available, so it was decided to use bolts made to the S.A.E., or, as it was then known, the A.L.A.M., standard. Using a working stress of 22,500 lb. per sq. in., this allowed the use of eight $\frac{7}{8}$-in. bolts in an $8\frac{1}{4}$-in. flange. This is open to the objection that a careless mechanic may replace these special bolts with standard bolts and thus cause the failure of the joint, but there has been no trouble from this cause.

11 When the piping was installed some of the gaskets were of soft copper and the rest of red fiber, but experience has shown red fiber to be more satisfactory as the copper soon hardens and a slight water hammer will often start the joints leaking, while the red fiber does not give this trouble.

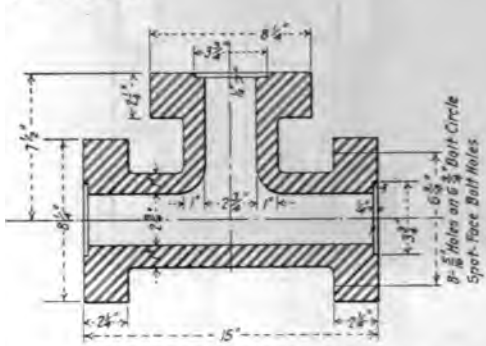

FIG. 2 TYPICAL FLANGED FITTING FOR 7500 LB. PER SQ. IN.

12 The system was to supply three machines from a group of five pumps, and the piping was to be so arranged that the large machine, which was to use pressures up to 7500 lb. per sq. in., could be operated with any or all of the pumps while the other two machines were to be operated with one or two pumps each, but the connections were to be so made that any pump could be connected to any machine. This was done by using a manifold tee on the discharge of each pump with a valve connecting to each pipe line.

13 The valves originally put in were of two types; one a wedge gate valve with cast-steel body and hard bronze wedge, the other a stop valve of the balanced type having a cast-steel body and bronze plunger. The gate valves proved impracticable as the bodies could not be made sufficiently rigid to prevent distortion of the seat and the starting of a leak which would grow very rapidly because of the cutting action of the water. The other valves were more satis-

factory and could be kept fairly tight by frequently dressing the seat and plug; but it was found more satisfactory to use blank flanges and pipe spools in place of the valves to make necessary changes in connections.

14 The machines were in effect single-acting presses in which the ram was returned by an auxiliary low-pressure system. The

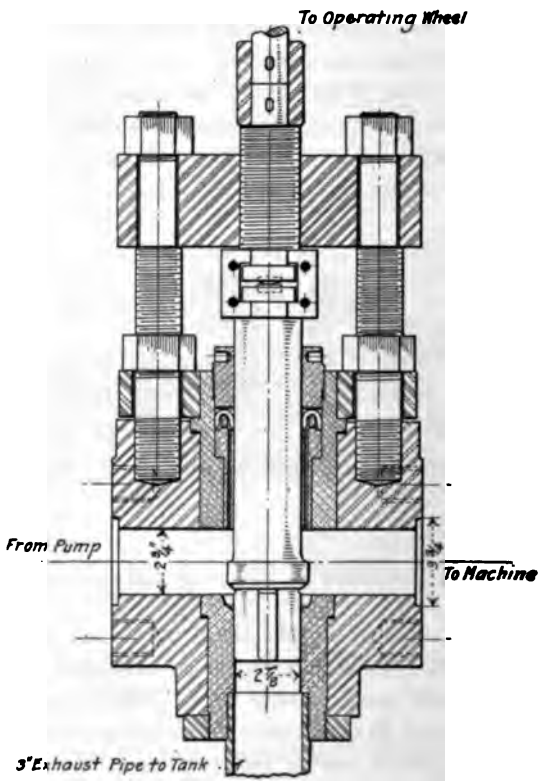

FIG. 3 OPERATING VALVE FOR 7500 LB. PER SQ. IN.

main operating valve therefore became a bypass valve which was closed to drive the ram forward and opened to allow the ram to stop and be returned. The valve in Fig. 3 was chosen for this place and was first made without the loose connection shown in the stem, but it was found very hard to open it after it had been shut tight, so the connection was added and this difficulty overcome. Experience had shown that the form of seat used with the beveled recess for the plug would last much longer than if the valve had a flat seat.

15 This system has been in use five years, often with a working pressure of 8000 lb. per sq. in. for short periods, with no failures and, with the exception of the valves mentioned, has given good satisfaction.

16 On two similar systems more recently installed for operating pressures of from 4000 to 5000 lb. per sq. in. the same type of pipe and fittings has also been used with success. The operating valves furnished for these systems were made as shown in Fig. 4

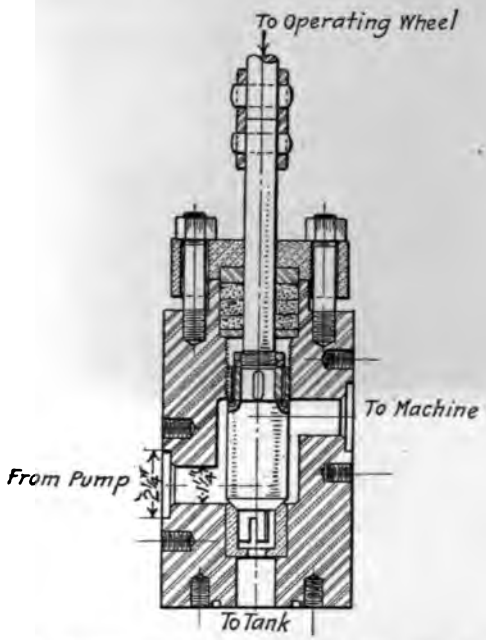

FIG. 4 OPERATING VALVE FOR 5000 LB. PER SQ. IN.
(Unsatisfactory Design)

and proved unsatisfactory, as the water pressure on top of the plug held the valve closed so that it was almost impossible to open it. These were replaced by valves similar to Fig. 3, which are working satisfactorily.

17 These machines had an exhaust valve as shown in Fig. 5 which returned the water direct from the main cylinder to the tank on the return stroke of the ram. These gave much trouble by the intermediate piece between the valve body and operating cylinder breaking through as indicated. This in two cases blew the operating

cylinder entirely off the valve body. Two of the valve bodies also failed by splitting. In view of this and the fact that a leakage through the U-leather packing might also blow the operating cylinder off, it was decided to redesign this valve, using a cast-steel body and cylinder arranged to eliminate these faults. Fig. 6 shows this valve, and, although it is rather difficult to build, it has proved very satisfactory in operation.

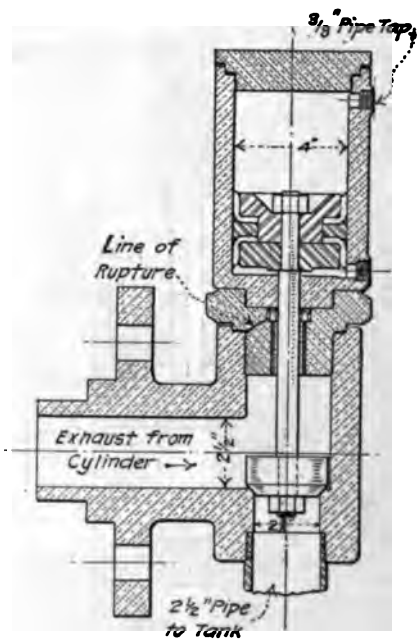

FIG. 5 EXHAUST VALVE FOR 5000 LB. PER SQ. IN.
(Unsatisfactory Design)

18 On a smaller press having three double-acting cylinders designed to operate in regular sequence, a multiple valve of the semi-balanced spring-closed type, shown in Fig. 7, was used, having the individual valves opened by bell-crank levers moved by face cams mounted on a common shaft. The cams were so arranged that rotation in one direction would cause the cylinders to operate in the proper order. The valve was so designed that when open the area through the seat was greater than around the stem, thus reducing the velocity of water through the seat and largely elimi-

nating the cutting of the seat. Fig. 8 is a key plan of Fig. 7. Fig. 9 is a section through one of the valve seats of Fig. 7, showing areas.

19 This press is connected directly to the pump through this valve and it has proved much more satisfactory than the four separate valves which it replaced, one bypass and three reversing, as a careless operator cannot work the valves in the wrong order and break the press.

20 The piston rod in the large cylinder of this press is two-thirds the diameter of the piston, and it was found that when the speed of the press was increased by speeding up the pump, the valve

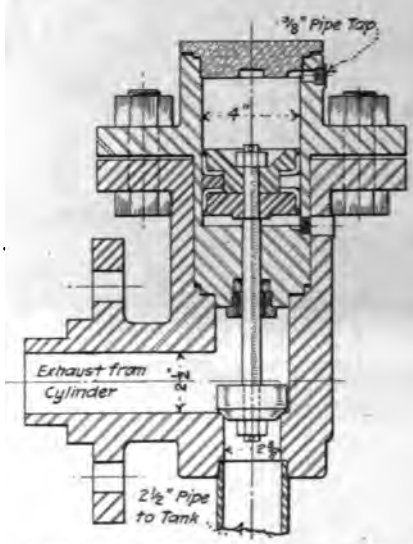

FIG. 6 EXHAUST VALVE FOR 5000 LB. PER SQ. IN.

controlling the head end of the cylinder was too small to allow the water to escape quickly enough on the return stroke of the ram to prevent a rise in pressure in the opposite end of the cylinder and consequent blowing of the relief valve at each stroke of the ram.

21 After considerable experiment it was decided that the best way to overcome this difficulty would be to devise some method of returning the water from the head end of the cylinder direct to the suction tank of the pump, on the return stroke of the ram. This was accomplished by inserting the valve shown in Fig. 10 in the pipe between the operating valve and the head end of the cylinder. As will be seen from the figure, the upper valve will open when water

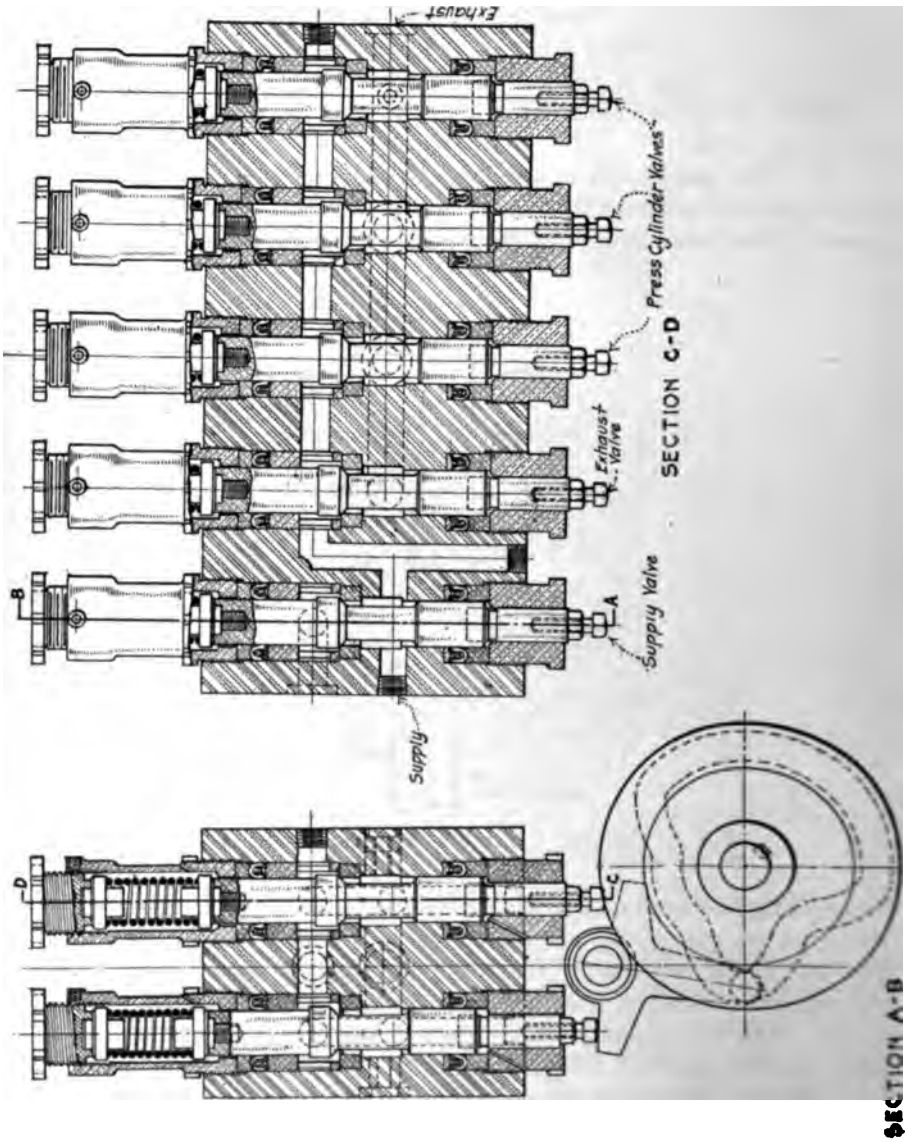

FIG. 7 MULTIPLE OPERATING VALVE (SEE KEY PLAN IN FIG. 8)

is admitted from the operating valve, while the lower valve will be held closed. When the pressure from the operating valve is relieved and the ram starts to return, the lower valve will open and the upper valve close, thus returning the water direct to the tank through the 2-in. pipe. This eliminated practically all trouble with the operating valve and materially increased the speed of the press.

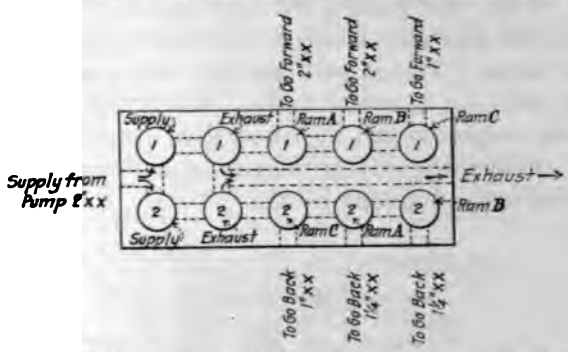

FIG. 8 KEY PLAN SHOWING ARRANGEMENT OF VALVES IN FIG. 7

22 As the highest pressure used in this system was 1500 lb. per sq. in., double extra strong pipe and malleable-iron extra heavy hydraulic screwed fittings were used and have proved satisfactory.

23 In designing valves and fittings for service on accumulator systems I have found that it is usually the severity of the water

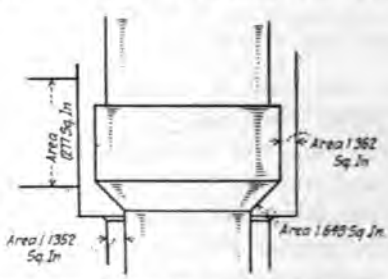

FIG. 9 SECTION THROUGH VALVE SEAT OF ONE OF THE VALVES IN FIG. 7, SHOWING AREAS

hammer rather than the actual pressure that determines the strength required, and that in laying out such a system all possible care should be used to avoid trouble from this source. However, as the severity of water hammer in a new system can never be exactly determined before it is in operation, I have used the designing formula given in the first part of this paper, with a working fiber stress of one-third

to one-half the elastic limit of the materials employed, depending on the probable severity of shock from this cause. This I have attempted to check by figuring the rise of pressure to be expected due to the inertia of the moving parts of the accumulator if all operating valves should be closed at the same time. This is done by assuming the ram of the accumulator to be coming down with a maximum velocity and figuring the force necessary to cause a negative acceleration sufficient to stop it in an assumed minimum time of closing the valves. This at best can only be a rough check, but it has proved sufficient in several cases. The piping of such a system should be so supported and anchored that water hammer will not cause any considerable whip in the piping, as this is the usual cause of broken fittings and leaking joints.

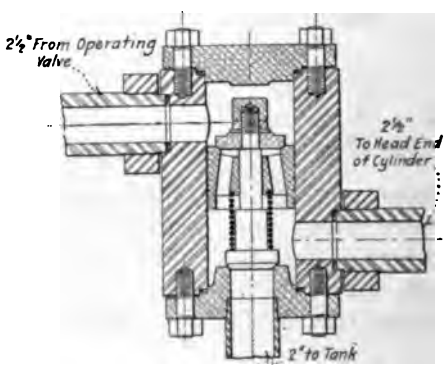

FIG. 10 VALVE FOR BYPASS TO TANK ON RETURN STROKE

24 The valve most used to control single-cylinder machines like draw benches on an accumulator system is a combined throttle and reversing valve, while the valves for multi-cylinder machines are too numerous and complex to describe in this paper, but the principles used in their design are the same as for the valves already described, except that greater care must be exercised to prevent too rapid opening and closing and consequent destructive water hammer.

DISCUSSION

CHARLES RAISIG (written). I have read the paper with a great deal of interest and wish to present formulæ I have used successfully and compare them with the formula employed by the author.

In all problems which I have encountered in practice, the fiber stress in a thick cylinder due to internal pressure may be figured as

for a thin cylinder if the pressure be considered as acting upon the external diameter instead of the internal diameter.

Barlow's simple formula:

$$\frac{P}{f} = \frac{t}{R}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [1]$$

in which R is the external radius, is not empirical. Its derivation is presented in Goodman's Mechanics, which also gives Lamé's formula as

$$\frac{P}{f} = \frac{R^2 - r^2}{R^2 + r^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

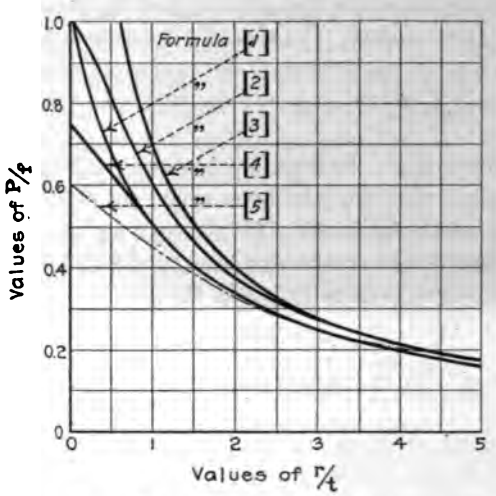

FIG. 11 COMPARISON OF FORMULÆ [1]–[5] FOR DETERMINING STRESSES IN THICK-WALLED CYLINDERS UNDER INTERNAL PRESSURE

A formula used by two well-known builders of large hydraulic and steam hydraulic forging presses is

$$\frac{P}{f} = \log_e \frac{R}{r}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

Tschappat in his book entitled Ordnance and Gunnery, develops the following formula, which he credits to Lamé:

$$\frac{P}{f} = \frac{3}{2} \frac{R^2 - r^2}{r^2 + 2R^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

This formula is rationally developed and is based upon maximum strain.

The formula presented by the author may be written as

$$\frac{P}{f} = 0.6\,\frac{R^2 - r^2}{R^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

In order to compare these various formulæ with each other they have been plotted as shown in Fig. 11, where it is seen that all the curves give practically the same result when the ratio r/t is equal to or greater than 3. Below 3 the curves diverge. Those for Formulæ [1], [4] and [5] lie well together, however, until the value of r/t has decreased to unity.

At the value of $r/t = 0.5$ the curve for formula [5] has diverged considerably from those for Formulæ [1] and [4], these latter, however, still agreeing very closely. Values of r/t below 0.5 are not liable to be used even for the exceedingly high pressures which occur in guns. For pressures up to 8000 lb. per sq. in. the ratio r/t is seldom smaller than 2.

In order to compare the results obtained by Formulæ [1] and [5] let us recalculate the two problems given by the author in Par. 8. Taking $2\frac{3}{4}$ in. inside diameter, 7500 lb. per sq. in. internal pressure and the safe fiber stress in the seamless tube as 27,000 lb. per sq. in., then, since $R = r + t$, from Formula [1]

$$(t + 1\tfrac{3}{8})\,7500 = 27{,}000\,t$$

from which $t = 0.53$ in. as compared to 0.51 in. from the author's calculation.

In the second problem, assuming the same conditions with the exception of the fiber stress, now 19,500 lb. per sq. in., $t = 0.86$ in. as compared to 0.925 in. obtained by the author.

Formula [4], the results of which can be obtained simply with sufficient accuracy by the use of Formula [1] for all values of r/t greater than 0.5, is the one used by the Army and Navy in gun design for pressures which are much higher than those under consideration. For this reason while the results obtained by using Formula [4] are less conservative than those obtained by employing the author's formula, [5], the writer believes that they are entirely safe.

I would particularly like to have the author publish more in detail the failures which he has observed in order to guide others as to the safe fiber stress to assume for different classes of high-pressure work.

A. A. Adler asked the author regarding the hypothesis he had employed in connection with the design around the flanges. Ordi-

narily the Lanza and other formulæ were based on the assumption of an exceedingly long cylinder.

EMMETT B. CARTER said that he had had considerable experience with hydraulic pressures up to 11,000 lb. per sq. in., and had found copper gaskets to be very satisfactory. In high-pressure work one former cause of valve failure had been the breaking of studs, particularly when subjected to water-hammer stresses. This he had successfully overcome by using studs made of a nickel-chrome composition.

R. J. S. PIGOTT asked the author what his experience had been with metallic packings, particularly those using shredded-lead mixtures. In his work he had found it satisfactory when properly set up, but when it disintegrated it traveled through the water system and caused trouble at the valves. Fibrous packings gave even more trouble. He had also met with success in using plain cast-iron rings as well as pistons, but not with steam.

THE AUTHOR, in closing, said that he noted that Mr. Raisig had compared the formula he had proposed with four others by plotting ratios of P/f and r/t and had found them much the same where r/t was equal to or greater than 3. He had also plotted these formulæ and several others and had found that for these values they all gave very nearly the same results. For values of r/t less than 2, however, there was a considerable difference, and for these conditions he felt justified in using the more conservative formula proposed.

In reply to Professor Adler, he would say that the results of the experiments of Cook and Robertson, mentioned in Par. 3 of the paper, showed a possible increase of from 5 to 15 per cent in short cylinders and that the difference between this and the "long pipe," as Lanza and the others called it, was so slight that it was hardly worth considering.

He had had but very little experience with the metallic packing referred to by Mr. Pigott. U-leather packing around the stems had given such satisfaction that he had continued using it. He had employed fiber packing on low-pressure valves, but his experience with it had been much the same as Mr. Pigott's.

No. 1678

THE RELATIVE CORROSION OF ALLOYS

By R. B. Fehr, Dayton, Ohio[1]
Junior Member of the Society

The paper opens with a discussion of the many factors and difficulties encountered in studying the problem of the corrosion of alloys, and the lack of properly standardized tests for obtaining relative corrodibilities. The various methods of expressing the results of corrosion tests are noted and their limitations pointed out. The author proposes a new method, in which the results are expressed as the per cent loss of unit volume for each unit of surface. The data obtained by different experimenters using different sizes of specimens, and materials of different densities, can thus be made fairly comparable, provided the other conditions of testing are essentially the same.

The results of some recent relative corrosion tests of various alloys show that in tap water and solutions of sea salt certain iron-nickel, copper-aluminum, and nickel-copper alloys are much superior to carbon steels and commercially pure iron, and that the corrosion decreases as the concentration of the salt solution increases.

The most important conclusion is that careful, refined laboratory tests involving a duration of several days to several weeks, may serve as a satisfactory compromise between the one- or two-hour "acceleration" tests and the long-time service tests.

It is hardly necessary to emphasize the great importance of the problem of corrosion. The large number of technical papers appearing on the subject and the enormous mass of data that has been collected are a sufficient testimonial to the truth of this statement. But in spite of the time and attention that has been given to this subject by technologists and scientists, comparatively few laws have been definitely established, and consequently the true theory of corrosion is still a matter of controversy. In the writer's opinion the chief reason for the slow rate of progress in solving the problem of corrosion lies in the fact that the majority of workers in this field of research have failed to realize the vast complexity of the problem, and have therefore not taken into account the large number

[1] The paper was prepared by the author when assissant professor of mechanical engineering at The Pennsylvania State College.

Presented at the Annual Meeting, December, 1918, of The American Society of Mechanical Engineers. The paper also forms Bulletin No. 27 of the Engineering Experiment Station of The Pennsylvania State College.

of factors involved. No two experimenters have used precisely the same methods of testing, and, furthermore, very few have stated the conditions of their tests with sufficient completeness to enable one to make comparisons or draw definite conclusions. It is therefore not surprising to find conflicting data and opinions, whereas the data may be entirely correct for the particular conditions under which they were obtained.

2 The obvious remedy for this state of affairs would appear to lie in the elimination of all variable factors, i.e., in the standardization of methods of testing. Undoubtedly there can be no one standard method for testing relative corrosion; neither can there be, nor is there, one standard method for testing the relative strengths of metals. But just as there are tension, compression, shear, torsion, bending and fatigue tests for determining the relative strengths of metals under different conditions of use, so, too, ought there to be certain standard tests for determining the relative corrosion of metals under different conditions. In order that the results obtained by different experimenters may be comparable and lead to definite conclusions regarding the laws of corrosion, standards should be adopted in regard to such matters as dimensions of specimens, preparation of surfaces, amount of corroding medium, method of suspension in medium, temperature, access of light, duration of test, diffusion, cleaning and weighing of specimen, method of expressing relative corrosion, and, perhaps most important of all, the nature of the corroding medium.

3 The ultimate aim should be to devise a comprehensive series of tests to which standard specimens of materials may be subjected, and by which the relative corrodibilities of these different materials may be predicted for certain service conditions. A great amount of systematic research work would have to be done before a satisfactory set of standards could be devised, but the problem is somewhat simplified by the fact that relative values of corrosion are desired rather than absolute values. Consequently, it will probably be found that a few tests will cover in a qualitative way the most usual conditions that are met with in practice.

4 One of the most important factors that would be involved in any proposed standard method is the time element. Although the best test of the usefulness of a material is, of course, the actual service test during a long period of time, no engineer would think of building a machine or structure without first making strength tests of samples of the materials used; and in like manner he would prefer

o have some comparatively simple means for determining the relaive corrosion of materials before deciding upon the best one to use ınder the particular conditions involved, without having to wait or the test of time on his completed structure.

5 To meet this short-time requirement various so-called "acelerated" corrosion tests have been devised, the principal corroding nedia being sulphuric acid, sea water or other salt solutions. These nethods have met with much opposition for the reason that they do ıot imitate, and therefore cannot intensify, natural corrosive influ-ınces, as they were intended to do. The results thus obtained are ıot in agreement with those obtained under practical service condiions. This is not surprising, for it is now becoming generally ecognized that the relative corrodibilities of different materials ary with the nature of the corroding media. What may be highly esistant under one set of conditions may be highly corrodible under ı different set of conditions.

6 Cushman and Gardner state in their book (page 99), on The Corrosion and Preservation of Iron and Steel:

> Owing to the nature of corrosion it is probably true that no perfectly relia-ıle acceleration test for corrosion resistance can be devised. Corrosion, in the ıatural process of rust formation, that is to say, in very slightly acid media, is a ıuestion of comparatively slow growth under special conditions, and any effort o hasten the action changes all the conditions of equilibrium, producing an en-ırely different order of phenomena.

7 In order to obtain the opinions of the Bureau of Standards ın the value of acceleration tests, the following questions were ıddressed to the Director:

a Is there any standard method for testing the relative corrosion of various metals?

b Do you have any confidence in acceleration tests?

8 The following replies were received:

a "There can be no standard method for testing the relative corrosion of various metals, since corrosion depends not only on the kind of metal but also on the nature and concentration of the corroding agent."

b "Acceleration tests are of value only if the conditions are produced under which the articles are to be used. Thus articles to be used in the salt air at the seashore or in sea water may to advantage be compared in the "salt-spray" test, but a salt-spray test might give very misleading results if used, for example, in judging roofing materials

in a smelter town when much SO_2 is present. Hot-water tests, acid tests, etc., must be interpreted with the utmost care."

9 Since accelerated tests are not regarded as trustworthy, and also since long-time tests are not feasible, it becomes necessary to adopt some compromise between the one- or two-hour period of accelerated tests and the many years of the actual service tests. Some preliminary tests conducted by the writer led to the conclusion that trustworthy results could be obtained within a period of a few weeks, provided analytical balances were employed and the same care exercised as in quantitative chemical analysis. Of course, small test specimens would have to be employed. The objection might be urged that small specimens would not be representative of the material, but duplicate or triplicate samples combined with greater uniformity of preparation and accuracy in weighing would more than offset this nominal disadvantage.

METHODS PREVIOUSLY EMPLOYED FOR CORROSION TESTS

10 Not only is it necessary to adopt standard methods of testing, but it is equally important to agree upon some uniform method of expressing the results. The following methods have been employed:

a Loss of weight (specimens of practically the same original weights)

b Per cent loss of weight

c Loss of weight per unit area of exposed surface

d Appearance as judged by the naked eye or lens.

11 Methods *a* and *c* do not give correct relative values of the corrodibilities of materials that differ appreciably in density. Method *b* does not have this objection, but like *a* it does not take into account important differences in the ratios of exposed surface to volume. Method *d* is merely qualitative and depends upon personal judgment, but is useful for cases of unequal corrosion, or pitting, as will be noted later.

PROPOSED METHOD FOR INDICATING RELATIVE CORRODIBILITY

12 Although experiments run under different conditions with respect to weight, density, and exposed surface of the specimens can never be considered strictly comparable, a much better measure of the relative corrodibilities of materials can be gained by applying the following method of reasoning:

13 Suppose, by way of example, that a certain corroding medium gave the results on specimens of different materials having dimensions as noted in Table 1.

14 This example is a somewhat extreme case, but it sometimes requires an extreme case to emphasize a point. A study of the results obtained by the three methods *a*, *b* and *c* is interesting in that they appear to indicate four, three, and two different values, respectively, for the relative corrodibilities, whereas, in reality the four materials have the same corrodibility, as further consideration will easily show.

15 What really matters in corrosion is the *volume of material removed in a given period of time from each unit of surface,* and not the loss in volume per unit of volume, nor the loss in weight per unit of surface, etc., for these latter methods do not take into account the differences in density and exposed surface of the specimens, which differences are certainly no fault of the materials. For instance, specimen No. 2 has the same density but twice the exposed surface of No. 1. If it were of the same material as No. 1 it would be expected to lose twice the weight, and yet it would be manifestly unfair to say that the relative corrodibilities are different, as indicated by methods *a* and *b*.

TABLE 1 ILLUSTRATIVE CORROSION RESULTS ON DIFFERENT MATERIALS

Specimen	Weight, grams	Volume, cc.	Surface, sq. cm.	Sq cm./cc.	(a) Loss, gr.	(b) Loss, %	(c) Loss, gr./sq. cm.
1	15	3	75	25	1.5	10	0.020
2	15	3	150	50	3.0	20	0.020
3	30	3	150	50	6.0	20	0.040
4	30	3	300	100	12.0	40	0.040

16 Again, No. 3 has twice the density of No. 2, and if it had the same corrodibility it should lose twice the actual weight, as well as twice the weight per unit of surface. Therefore, provided all other conditions were the same in these cases, the only method that would indicate equal corrodibility would be method *b* on account of the canceling out of the density factors.

17 Obviously, then, none of the methods employed thus far indicates the true relative corrosion values for specimens of different sizes from different materials. However, if the results obtained by method *b* in Table 1 are divided by the respective values for the

ratio of surface to volume, the results will be 0.40 per cent cu. cm per sq. cm. in each case, and thus a true measure of the relative corrodibility is obtained.

18 The algebraic derivation of this method is as follows:

Let a = area of *exposed* surface of test specimen, sq. cm.
v = volume of specimen, cu. cm.
d = density of material, grams per cu. cm.
w = original weight of specimen, grams
s = loss in weight in grams by method a
p = per cent loss in weight, and volume, by method b
K = measure of relative corrosion by proposed method, per cent of cu. cm. per sq. cm. of surface.

$$p = \frac{s}{w} \times 100 = 100\frac{\frac{s}{d}}{\frac{w}{d}} = 100\frac{\frac{s}{d}}{v} = \text{per cent loss of volume,}$$

since the volume equals weight divided by density.

$$\frac{a}{v} = \text{ratio of surface to volume,}$$

and

$$\frac{p}{\frac{a}{v}} = 100\frac{\frac{s}{d}}{v} \times \frac{v}{a} = 100\frac{\frac{s}{d}}{a} = \text{per cent of cu. cm. lost per sq. cm. of surface.}$$

Therefore, $K = \frac{p}{\frac{a}{v}}$; that is, the per cent loss in weight (or volume) is to be divided by the ratio of surface to volume.

19 These values of K will then represent the true relative corrodibilities when the conditions of testing are the same except for the densities and dimensions of the specimens. But finally, in order to express in the simplest and most easily comprehended manner the relative values of different materials in regard to their *resistances to corrosion*, the reciprocals of the K values should be taken and compared with, say, the highest one, which, for the sake of comparison, may be regarded as having a corrosion resistance of 100 per cent. Thus, if materials A, B, C, and D have values for K of 5, 10, 15, 20, respectively, the reciprocals or resistances to corrosion will be 0.2, 0.1, 0.067, and 0.05; while the relative "efficiencies" of resistance to corrosion will be 100, 50, 33⅓, and 25, respectively.

20 This new method of expressing relative corrodibilities takes

into account the obvious fact that corrosion varies directly as the exposed surface, other things being equal. The time element cannot be involved in any method of expressing corrosion, for it is a well-established fact that corrosion does not vary directly as the time, since the first layers of corrosion products may in some cases inhibit, and in other cases accelerate, corrosion. In other words, the duration of all tests that are to yield comparative results should be a constant quantity.

A SERIES OF COMPARATIVE CORROSION TESTS

21 It is believed by the writer that careful tests of different sizes of specimens of various kinds of materials run under like conditions will justify the above proposed method of expressing the results, but as yet no such series of tests can be offered. Nevertheless, it may be of interest to report the results of a series of tests that were run for the purpose of ascertaining the consistency of results that could be obtained by exposing small-size specimens to tap water and solutions of sea salt for comparatively short periods of time. These tests are to be regarded as preliminary, and therefore the arbitrary conditions adopted will be subject to such future modifications or drastic changes as any inconsistencies in results of these and succeeding series of tests may indicate.

TABLE 2 ANALYSES OF ALLOYS

	A	*B*	*C*	*D*	*E*	*F*	*G*
	Percentages						
Fe	99.84	2.30	98.473	98.697	Trace	67.406	99.647
C	0.01	.....	0.78	0.459	.....	0.19	0.04
Mn	0.025	1½–1¾	0.594	0.74	.....	1.35	0.26
Si	0.005	.....	0.065	0.06	.....	0.184	0.01
S	0.025	.....	0.055	0.035	.....	*S* and *P* less than 0.04	0.036
P	0.005	.....	0.013	0.009	.....	.....	0.007
Cu	0.05	30.02	.....	.....	89.84	.....	.....
Ni	.....	65.48	.....	.....	.....	30.83	.....
Al	.....	.....	.....	.....	9.96	.....	.....
Ti	.....	.....	0.02	.....	.....	.....	.....

22 A number of commercial alloys were supplied by various manufacturers who were interested in seeing a series of tests run by experimenters who had no interest in any industrial concern. The

analyses of these alloys, as made by the manufacturers, are found in Table 2.

23 The alloys were supplied in the form of $\frac{3}{4}$-in. rolled stock, which was turned down in a lathe, and from which were cut disks of fairly uniform size as shown by the data in Table 3.

24 A $\frac{1}{8}$-in. hole was drilled in the center of each specimen in order that a glass hook could be inserted for suspending the specimen in the corroding medium. All the specimens were first roughly polished by emery cloth and then finished to uniform surface conditions by rouge cloth. The disks were then washed in ether to remove all grease, dried in a dessicator, and carefully weighed on analytical balances.

TABLE 3 DATA ON TEST SPECIMENS[1]

Average diameter, inches	0.6000
Average thickness, inches	0.1544
Average weight, grams	7.604
Average ratio of surface to volume $\left(\frac{s}{v}\right)$	20.04
Average per cent deviation of $\frac{s}{v}$ from mean	4.6
Maximum " " " " " " "	13.8
Minimum " " " " " " "	0.12

[1] As obtained after the series of tests.

25 The following solutions were employed:

a Tap water

b 0.1 per cent sea-salt solution (one gram of sea salt per liter of tap water)

c 10 per cent sea-salt solution (100 grams of sea salt per liter of tap water).

26 In order to insure uniformity of corroding media throughout the entire series of tests, sufficient amounts of the solution were made up and put away in tightly stoppered bottles.

27 The tests on the various alloys and three solutions were run simultaneously with duplicate specimens. A 150-cc. beaker filled with 100 cc. of the corroding solution was provided for each individual specimen, which was suspended in the middle of the solution by means of a glass hook attached to a short piece of wood resting on top of the beaker. At the end of the one-day (24-hour) test the specimens were removed from the beakers, soaked for several hours in a solution of ammonium citrate in order to remove the rust, dried and carefully weighed to determine the loss in weight. The specimens were then polished so as to have new surfaces, cleaned,

dried and weighed for the succeeding seven-day test, for which new solutions were employed. This procedure was maintained for the 28- and 105-day tests. In all cases the beakers were placed in a glass case, and the daily maximum and minimum temperatures were observed.

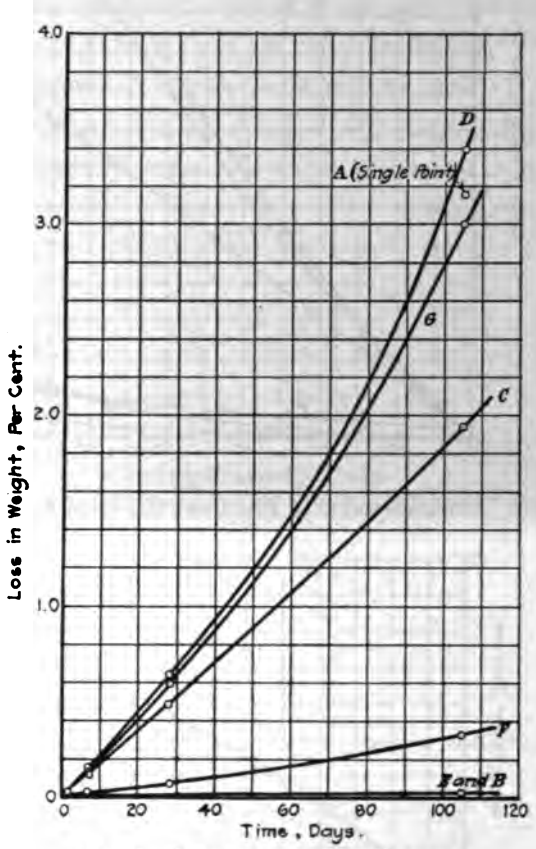

FIG. 1 CORROSION IN TAP WATER

RESULTS

28 In expressing the results of these tests, the percentages of loss by weight (Table 4) were plotted in Figs. 1, 2 and 3, rather than the values of K as proposed above, for the reason that the ratios of the surface to volume were practically the same, the average deviation from the mean being only 4.6 per cent. In Figs. 4, 5 and 6 are plotted the relative efficiencies of resistance to corrosion (Table 5) as previously explained in this paper, the alloy

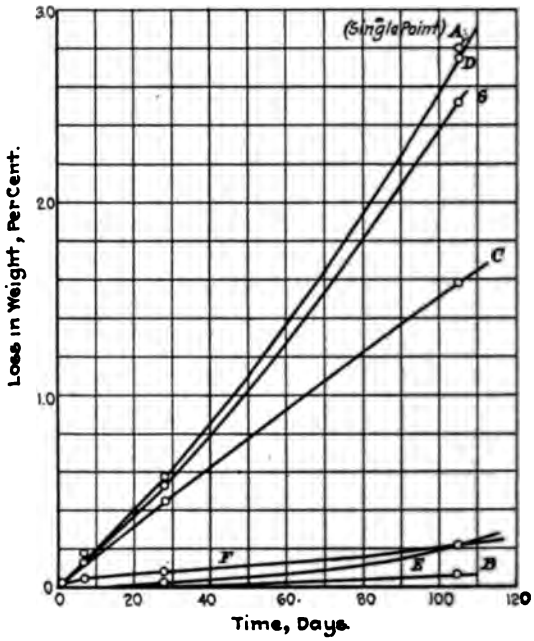

FIG. 2 CORROSION IN 0.10 PER CENT SEA-SALT SOLUTION

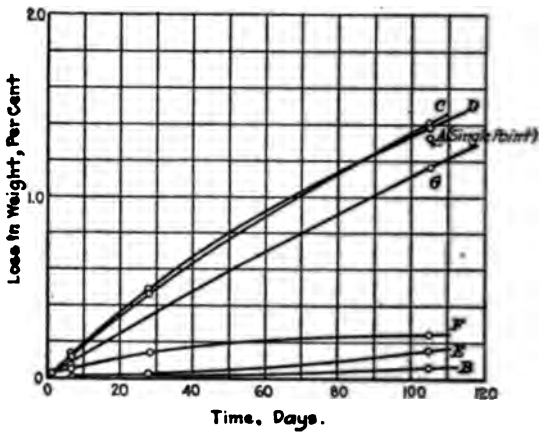

FIG. 3 CORROSION IN 10 PER CENT SEA-SALT SOLUTION

marked *F* being taken as the 100 per cent standard in this case. Alloys *B* and *E* exhibited such a slight amount of corrosion that they could not very well be used as a basis for comparison. Table 6 gives some statistical data of these tests.

DISCUSSION OF RESULTS

29 Among the points to be noted as a result of these tests are the following:

30 The most impressive feature, as seen in the curves of Figs. 1, 2 and 3, is the consistent grouping of the more corrosive iron and steel alloys *A*, *C*, *D* and *G*, as against the highly resistant alloys

TABLE 4 PERCENTAGES OF LOSS BY WEIGHT
(AVERAGES OF DUPLICATE TESTS)

	1 Day	7 Days	28 Days	60 Days [1]	105 Days
			Tap Water		
A	.....	.....	.....	.....	3.16
B	.....	.....	0.000	0.007	0.028
C	0.028	0.142	0.494	1.08	1.95
D	0.033	0.165	0.629	1.49	3.39
E	.....	.....	0.000	0.009	0.029
F	0.012	0.016	0.073	0.170	0.33
G	0.035	0.150	0.597	1.41	3.00
			0.1 Per Cent Sea-Salt Solution		
A	.....	.....	.....	.....	2.80
B	.....	.....	0.006	0.021	0.061
C	0.034	0.153	0.449	0.93	1.59
D	0.031	0.183	0.570	1.35	2.75
E	.....	.....	0.022	0.066	0.216
F	0.022	0.040	0.077	0.134	0.213
G	0.043	0.149	0.530	1.26	2.52
			10 Per Cent Sea-Salt Solution		
A	.....	.....	.....	.....	1.34
B	.....	.....	0.0013	0.011	0.062
C	0.026	0.116	0.466	0.91	1.40
D	0.027	0.123	0.492	0.92	1.37
E	.....	.....	0.034	0.080	0.162
F	0.021	0.065	0.136	0.192	0.238
G	0.027	0.091	0.349	0.699	1.17

[1] From curves.

B, *E* and *F*, in which copper and nickel are the most prominent constituents. In the first group it should be noted that the steel *C*, in which titanium is employed as a cleanser, shows considerably less corrosion than the other steels in tap water and weak salt solutions. In the second group the copper-nickel alloy *B* was in most

cases superior and in no case inferior to all the other alloys. This was the only alloy that exhibited its original appearance after being cleaned in the ammonium citrate solution.

31 Perhaps the next most impressive fact brought out by these tests is the decreased corrosion of the more corrosive group of alloys

TABLE 5 RELATIVE EFFICIENCIES OF CORROSION RESISTANCE[1]

	1 Day	7 Days	28 Days	60 Days	105 Days
			Tap Water		
A	.....	.....	.....	.....	10.4
B	.....	.....	∞	2430.0	1120.0
C	42.9	11.3	14.8	15.8	16.9
D	36.4	9.7	11.6	11.4	9.74
E	.....	.....	∞	1890.0	1140.0
F	100.0	100.0	100.0	100.0	100.0
G	34.3	10.7	12.2	12.1	11.0
			0.1 Per Cent Sea-Salt Solution		
A	.....	.....	.....	.....	7.61
B	.....	.....	1284.0	633.00	349.0
C	64.7	26.1	17.2	14.40	13.40
D	71.0	21.9	13.5	9.92	7.75
E	.....	.....	350 0	203 00	98.00
F	100.0	100.0	100.0	100.00	100.00
G	51.1	26.8	14.5	10.60	8.46
			10 Per Cent Sea-Salt Solution		
A	.....	.....	.....	.....	17.7
B	.....	.....	10460.0	1745.0	384.0
C	80.7	56 0	29.2	21.1	17.0
D	77.7	52.8	27.6	20.9	17.4
E	.....	.....	400.0	240.0	147.0
F	100.0	100.0	100 0	100.0	100 0
G	77.7	71.4	39.0	27.5	20 4

[1] As calculated from Table 4.

as sea salt is added to tap water. This effect is not observed in the non-corrosive group of alloys, for the reason that it is probably masked by experimental errors in determining the very slight losses in weight. This decreased corrosion with increased concentration of the salt solution is in harmony with the results of other experimenters, notably Friend and Barnet.[1]

[1] The Corrosion of Iron in Aqueous Solutions of Inorganic Salts, by J. Newton Friend and Peter C. Barnet, Journal of the Iron and Steel Institute, 1915, I p. 336.

32 The slight upward concavity in the curves of the more corrosive alloys in the tap water and 0.1 per cent sea-salt tests may possibly find explanation in the fact that in the long-period tests the solution evaporated considerably, with the result that the specimens had a less average depth of immersion and consequently greater access to atmospheric oxygen. In fact, by the end of the 105-day test the solutions had evaporated to such an extent that the specimens were in some cases slightly exposed to the air. This accelerative effect of lower depths of immersion apparently did not take place appreciably in the more concentrated solutions, which had a considerably less corrosive effect.

33 The commercially pure iron *A*, which was received in time for only the 105-day test, gave very disappointing results, since in all three corroding media it showed practically the same corrosion as

TABLE 6 STATISTICAL DATA OF TESTS

Duration of Test, Days	1	7	28	105	Average
Average per cent deviation of per cent loss (p) from mean of duplicate tests	3.21	5.85	4.94	4.22	4.56
Average per cent deviation of values of *K* from mean of duplicate tests	3.80	5.01	5.25	3.67	4.43
Average daily maximum temperature (deg. fahr.)	.....	76.2	79.5	78.3	.....
Average daily minimum temperature	.....	65.3	67.4	66.4	.....
Highest temperature reached	71.0	84.0	86.0	89.0	.....
Lowest temperature reached	54.0	62.0	60.0	52.0	.....
Average temperature (estimated)	62.5	70.8	73.5	72.4	.....

the ordinary carbon steels, *D* and *G*. However, in fairness it should be pointed out that rust may either accelerate or inhibit corrosion. If the metal is homogeneous, sound, dense, and free from occluded gases, the rust will probably be dense and closely adherent and will thus offer some degree of protection. If the metal is non-homogeneous and contains a considerable amount of occluded gases, the latter upon escaping will cause the rust to become spongy and porous, and will therefore permit the electrolyte to come more readily into contact with the metal. In the case of the practically pure iron *A*, only one test (105 days long) was run, and consequently no curve of results could be obtained. Perhaps tests of longer duration would indicate *A* to be superior to *D* and *G*, especially as regards pitting, but for the present it can only be concluded that, from the standpoint of loss of weight, commercially pure iron is not superior to steel in tap water and salt solutions.

34 The specimens did not show any pitting, but in most cases, after the corrosion products had been washed off, there remained stains and slight blotches, except in the case of *B*, which showed only a very slight yellow-red stain in the salt solutions, but which

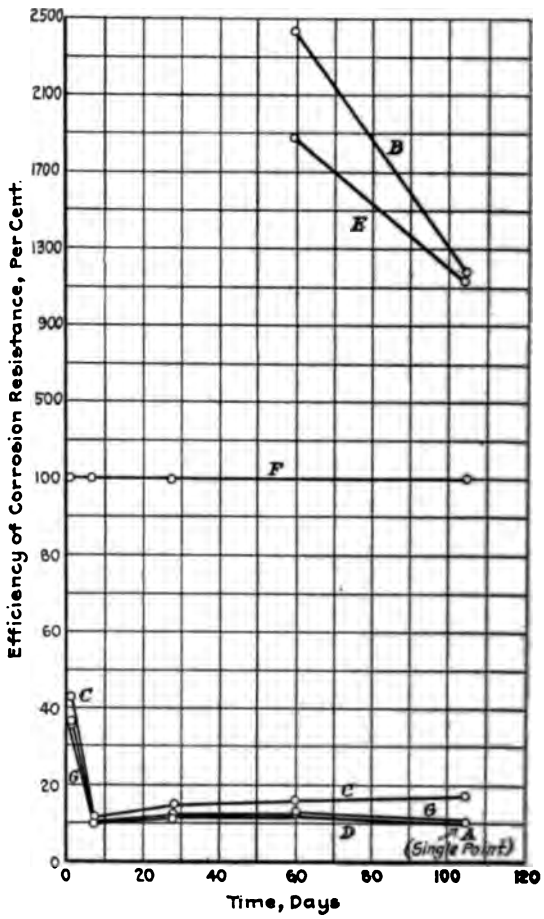

FIG. 4 RELATIVE EFFICIENCIES OF CORROSION RESISTANCE IN TAP WATER

was easily removed with the result that the metal showed its originally bright appearance. It must be kept in mind that no quantitive method of measuring corrosion is satisfactory in the case of materials that become pitted, for it may very likely happen that a badly pitted specimen may show but a comparatively small loss in

weight. Consequently it is always important to accompany the quantitative tests with the qualitative test of the appearance.

35 A study of the statistical data of Tables 3 and 6 points to the conclusion that when corrosion specimens are fairly uniform in

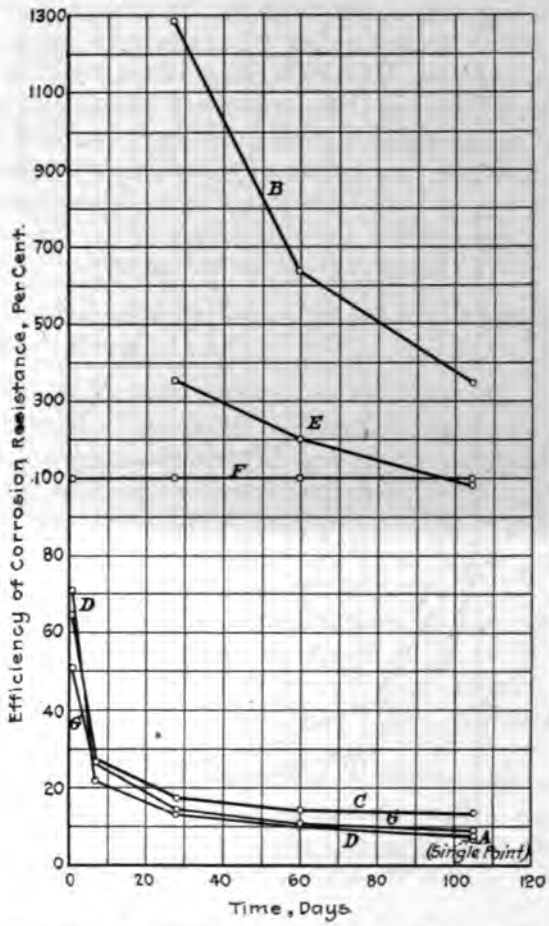

FIG. 5 RELATIVE EFFICIENCIES OF CORROSION RESISTANCE IN 0.10 PER CENT SEA-SALT SOLUTION

density, area of exposed surface, and volume, the method of expressing the relative corrosions by per cent loss in weight gives results as consistent as those obtained by the newly proposed method, for the average deviations of both methods, as noted in Table 6, are practically equal. It should be kept in mind, however, that the use of

the new method, in cases where the specimens vary considerably among themselves with regard to density or ratio of surface to volume, will give a much better basis for comparison than any other method.

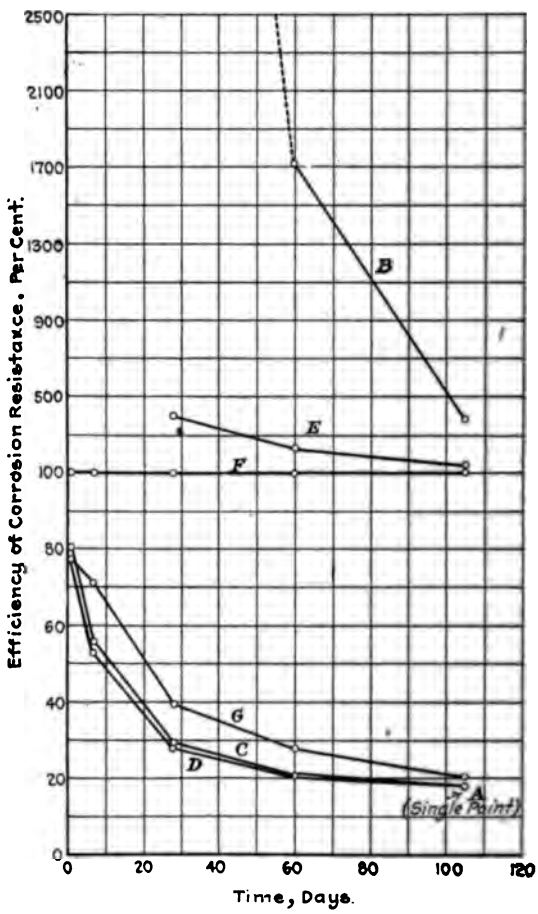

FIG. 6 RELATIVE EFFICIENCIES OF CORROSION RESISTANCE IN 10 PER CENT SEA-SALT SOLUTION

36 The relative efficiencies of corrosion resistance as shown graphically by Figs. 4, 5 and 6, indicate that very consistent results can be obtained by the method of testing employed in these series, when the duration of the test is one week or more for the more corrosive alloys, and about one month or more for the less corrosive

alloys. In fact, one day is quite sufficient to classify groups of alloys in the order of their corrodibility for such corroding media as will cause enough loss in weight to be determined by analytical balances. Nevertheless, before any final conclusion can be drawn as to the best method of testing relative corrosion, more work will have to be done, especially with reference to the results of service tests as compared with laboratory tests similar to those described in this paper. For the present, however, it seems proper to conclude that very consistent results (at least among themselves) can be obtained by using small specimens and refined methods, but without using "accelerating" conditions.

SUMMARY OF CONCLUSIONS

37 The conclusions to be drawn from the results obtained may be summarized as follows:

a Steels and commercially pure iron are very much more corrosive than nickel-steel (containing a high percentage of nickel), nickel-copper, and copper-aluminum alloys, in tap water and sea-salt solutions

b Titanium-treated steels appear to be somewhat more resistant to corrosion than the ordinary commercial steels in tap water and weak sea-salt solutions

c In general, the corrosion decreases as the concentration of the sea-salt solution increases

d Commercially pure iron does not show superior resistance to corrosion in laboratory tests of three months' duration

e Refined laboratory tests of short duration on small specimens under *natural conditions of corrosion*, can probably be devised to give results consistent with the order of corrodibility as determined from service tests of long duration

f The method of expressing relative corrosion by dividing the per cent loss in weight by the ratio of surface to volume should be employed when the test specimens are not within, say, 15 per cent of the same density or size

g The quantitative method of measuring corrosion should always be accompanied by the qualitative test, based on the appearance of the specimen, in order to detect pitting or other irregularities on the surface.

ACKNOWLEDGMENT

In 1913 Dr. J. P. Jackson, formerly Dean of the School of Engineering, Pennsylvania State College, suggested to the writer that a research be conducted on the corrosion of steels and other alloys. The necessary equipment was gradually accumulated and a series of tests was run during Prof. J. A. Moyer's incumbency as Acting Director of the Engineering Experiment Station. The publication of the report of this work is due largely to the interest and coöperation of R. L. Sackett, Dean of the School of Engineering.

The writer also desires to acknowledge the services rendered by M. P. Helman and G. S. Long, who prepared the specimens and obtained much of the data; and by E. F. Grundhoeffer, who, with the assistance of A. A. Bawiec and L. S. Longenecker, made many of the calculations and drew the curves.

Finally, the writer wishes to record his grateful appreciation of the criticisms and suggestions made by Prof. M. M. Garver, Associate Professor of Physics, who very kindly read the manuscript.

DISCUSSION

ALLERTON S. CUSHMAN[1] (written). I have read Mr. Fehr's paper with the closest attention, as the subject of acceleration tests as a measure of the corrosion resistance of metals has interested me for many years.

Speaking for myself, I long since reached the conclusion that small laboratory immersion tests on the beaker scale of operation were worse than useless, for the information yielded often leads to conclusions quite the opposite of the truth. I remember particularly a series of immersion tests in ammoniacal solutions which had led to the conclusion that iron and steel were uncorrodible in such media, when I was shortly afterward confronted in consulting practice with the experience of an industrial concern which had run into serious damage owing to the peculiar and dangerous corrosion of a series of steel vessels in which ammoniacal solutions were contained. After investigating this case, I lost confidence in my laboratory immersion tests.

Of course, where the degree of corrosion resistance is very marked as between, for instance, cupro-nickel and ferrous metals, the difference can be easily shown in immersion tests, but in such cases the difference in resistance is so obvious that tests seem almost unnecessary. When it comes to determining whether a given ferrous metal will outlast another under the average service conditions which such metals are called upon to meet, it is my belief that no accelerated

[1] Lieut.-Col., U. S. A., The Institute of Industrial Research, Washington, D.C.

test will ever imitate in a short time the record that metals of similar manufacture have given throughout years of service under all kinds of conditions. I have in mind a kind of steel that shows up well under test exposure to acid atmospheres or solutions, but under conditions which are practically neutral or slightly alkaline shows no better than ordinary grades of commercial steels. It does not seem to me that the measurement of loss of weight of small samples of metal immersed in artificial corroding media should be used for calculating any sort of coefficient of corrosion resistance, unless the conditions of the test duplicate the conditions of some special service which it is expected to encounter. When such is the case, however, I like the method which the author suggests for handling and recording the numerical data. In this connection, however, it should never be forgotten that small cut samples in a beaker may not point the way that big commercial units made from the same kind of metal are going to behave in service.

I agree with the author that in immersion tests salt solutions of high concentration are much less corrosive than solutions of less concentration, but I can not conclude from this that if the Atlantic Ocean was more or less salty than it really is, we should no longer have to face serious corrosion problems at sea.

I would also like to refer to what seems to me to be a point that is too often overlooked in the discussion of accelerated-corrosion tests. This is that a metallurgical product made to a specified chemical analysis may vary widely in corrosion resistance, due to failure to maintain constant or standard physical conditions in separate heats from the same furnace. This variation may be due to climatic or atmospheric changes, to lack of uniformity in available raw materials, or to human error. Due to these and other variables, all well known to metallurgists but too numerous to mention here, the results obtained in small acceleration tests may appear favorable or the reverse, according to the chance selection of the material under investigation. It should be constantly borne in mind that the gases absorbed by metals in the course of manufacture have a decided bearing on corrosion problems, but these gases are almost never considered in this relation and present the greatest difficulty to the chemist in their recognition and determination. Resistance to corrosion of any given metal is therefore typical, rather than individual to any given sample under any given acceleration test.

The author's conclusion that steels and commercially pure iron are very much more corrosive than nickel steel (containing a very

high percentage of nickel), copper-nickel and copper-aluminum alloys in tap water and sea-salt solutions, is undoubtedly justified, but, on the other hand, we have to remember that these different grades of metal rarely come into commercial competition with each other, as they are not made for the same purposes or sold within the same range of prices. It could equally as easily be discovered that platinum and gold were less corrosive than nickel steel containing a high percentage of nickel.

In regard to the author's final conclusion that quantitative methods of measuring corrosion should always be accompanied by qualitative tests based on the appearance of the specimen, in order to detect pitting or other irregularities on the surface, here we also find ourselves up against a difficulty, since the quality and kind of pitting which takes place depend entirely on the nature of the attack under service conditions, so that one and the same metal may show an entirely different quality in this respect under one sort of service from what it would show under another. However, Mr. F. N. Speller, metallurgical engineer with the National Tube Company, has made very valuable studies in regard to the pitting of pipes under various kinds of service and has published quantitative methods of following this particular phase of the corrosion problem. Some of them have been published, I believe, in the Transactions of the American Society for Testing Materials.

J. H. Norris said that the corrosion of non-ferrous alloys by weak saline or alkaline solutions could be expedited by bringing the two samples into contact and then separating them. In his business, use was made of a gear train working in tap water. Tap waters varied a great deal over the country and in some cases gear trains running in them would be entirely corroded in two months. This he attributed to electrolytic action between the gears. The fast-running gear would not corrode, while the slow-running one corroded so rapidly that it had to be replaced in a very short time. He thought that any experiment on the corrodibility of alloys should take the foregoing observation into account.

Benjamin J. Colvin related his experience with a 5000-gal. hot-water heater provided with the usual internal brass-pipe coil. This heater, after serving a dye house for two years, began to corrode rapidly, and inasmuch as daily analyses showed the water to be soft and very uniform throughout the year, it occurred to him that the

corrosion might be due to electrolysis. Tests having shown a difference of potential of 0.02 volt between the shell and the coil while the heater was in service, the shell of the heater and the brass coil were connected by several No. 0000 jumpers, this being the old method for preventing the corrosion of underground water pipes by leakage from electric-railway tracks. Six months later the heater was taken apart and it was found that not only had the action ceased but it had been reversed and the pit holes were filling up. Inspection at a later date showed that the holes had been completely filled up with what appeared from a field examination to be the substance of the plate. Samples from some of the refilled pits were chipped out with a cold chisel and compared under a microscope with particles chipped from the plate. So far as could be determined from this examination, both samples were of the same characteristics. An examination of the coils by members of the operating force and the inspector of the Hartford Steam Boiler Inspection and Insurance Company, showed no deterioration of the coil beyond that of ordinary wear and tear.

James F. Howe told of a problem presented in his work in which galvanized steel and iron and a small mass of zinc were all in contact in sea water, which corroded the latter metal. As it was desired to prevent this, an alloy was sought which could be used with zinc and iron and would be electropositive to neither. This was found in a composition of 15 per cent of antimony and 85 per cent of lead, which, when tested with a millivoltmeter in a saturated saline solution, showed practically no deflection — nearly all other alloys tested showing 0.2 to 0.4 volt.

Robert L. Sackett said that there might be electrolytic action involved in corrosion such as took place by current straying between street-car rails and water pipes, and there might also be electrostatic action. The situation did not depend upon exterior conditions at all or upon metals in contact. Wherever there was chemical action it might be accelerated or retarded by certain rather delicate electrical conditions.

Mr. Howe had made his measurements with a millivoltmeter. It was necessary in a refined discussion to deal with very small currents which might have a very considerable effect, but as a practical problem in the corrosion of specimens they were not of so much importance.

THE AUTHOR. The criticisms and suggestions made by those who took part in the discussion of the paper are appreciated by the author, who wishes to make brief reference to three matters which suggest the trend of the discussion, namely, "acceleration tests," "laboratory immersion tests," and "electrolysis."

In order that Dr. Cushman's frequent reference to acceleration tests may not leave the impression that the author of the paper is an advocate of such tests, it may be well to call attention to Pars. 5, 9, 36 (last line) and 37*e*, which were intended to emphasize two points concerning the author's position in this matter, namely:

1 Acceleration tests can not be regarded as trustworthy

2 Corrosion tests of a few days or weeks, run under natural conditions but with refined methods of manipulation and observation, can probably be devised as a satisfactory compromise between the short-time acceleration tests and the long-time service tests.

To avoid any misunderstanding as to the meaning of "acceleration" in corrosion tests, mention should be made of the fact that, although the so-called acceleration tests employed by various investigators have been of only a few hours' duration, the author believes that the idea of acceleration refers primarily to the intensified corrosive influences rather than to the shortened time that was required by the corroding media to produce appreciable effects. In other words, if a test were conducted on a metal under service conditions for a very short period of time, it could not be called an "acceleration" test, for the reason that the corrosion was not accelerated.

With reference to "laboratory immersion tests," the author desires to state that if he were to employ this expression, he would want the terms "laboratory" and "immersion" to be interpreted broadly. For instance, corrosion tests of small samples exposed outdoors to carefully observed weather conditions, but prepared, cleaned, and weighed under the best conditions obtainable in a laboratory, may well be called laboratory tests (see Par. 37*e*); and as for the term "immersion," all corrosion tests are really immersion tests, whether made outdoors or in the laboratory, for a test specimen may be regarded as being immersed in a gas, such as air, as well as in a liquid.

However, even though the term "laboratory immersion tests" was used in a restricted sense, as was evidently intended by Dr. Cushman, the author would not agree that such tests are "worse than useless," any more than technical and scientific men would

concede that chemical and physical analyses of metals are worse than useless. It seems reasonable that the scientific laboratory should solve many of the problems relating to corrosion, just as it has placed the iron and steel industry, for example, on a firm scientific basis. Certain it is that in a matter involving as many variables as corrosion does, no real progress can be made until the relative effects of these many variables can be determined individually by tests, run under the carefully controlled conditions that can be obtained in a laboratory. In the cases where the service tests do not appear to agree with the results obtained in the laboratory, it is of course quite likely that the latter were misinterpreted or that the conditions of the service tests were not correctly analyzed, with the consequence that unforeseen or unobserved factors have completely masked the effects of the factors that had been tested in the laboratory.

As for the size of test specimens, it is just as necessary to employ small sizes (but not necessarily as small as those used by the author) as it is to use small samples in quantitative chemical analysis, if accurate results are to be obtained. The author is aware of the many difficulties encountered in obtaining uniform metal products, and appreciates the fact that the corrosion resistances of samples of alloys having essentially the same chemical analysis may vary considerably, but at the same time he desires to suggest that it ought to be possible to select a number of small representative samples from large commercial units, just as it has been found practicable to select representative tensile-test bars.

Concerning electrolysis it may be stated that all cases of corrosion are really the result of electrolytic action, according to the most widely accepted theory. A great amount of work has been done along this line. For those who desire to study this important phase of the problem, the following sources of information will be found of especial interest:

The Corrosion and Preservation of Iron and Steel, by Cushman and Gardner.

Theory of the Corrosion of Iron and Steel, by L. Aitchison, Journal of the Iron and Steel Institute, 1916, I, p. 77.

Technologic Papers of the Bureau of Standards.

No. 1679

MECHANICAL FEATURES OF THE VERTICAL-LIFT BRIDGE

By Horatio P. Van Cleve, New York, N. Y.
Member of the Society

This paper covers the important developments in the operating mechanisms of the vertical-lift bridge, beginning with the Halsted Street bridge built for the city of Chicago in 1892, and ending with the 1600-ton lift span of Bridge 458, Pennsylvania Lines West, completed in the same city in 1914. It is shown that the improvements in design made in the 22 years intervening between the erection of these bridges were due not only to the observation and correction of faults, but to the fact that great progress was made during the same period in certain manufactured articles, principally the electric motor.

The writer mentions points of special interest in the design of eight lift bridges, describing supporting, guiding, and locking details, and methods of erection, operation, and control. On a certain type of tower sheave it developed, after one of the bridges had been put in operation, that the disk plates forming the webs of the sheaves were loose and moving on the steel hubs to which they had been riveted, and a satisfactory method is illustrated of overcoming the difficulty between operations of the span.

The erection of the lift span of Bridge 458, Pennsylvania Lines West, presented some unusual problems, and this work, with the unique method of solving one of these problems, is covered in considerable detail.

PRIOR to the year 1892, movable bridges of the elevator or vertical-lift type were practically unheard of. A few very short and unimportant spans of low lift had been built, but in that year a bridge, much more pretentious than anything so far attempted, was built in Chicago from the designs of Mr. J. A. L. Waddell, Consulting Engineer, of Kansas City, Mo. This bridge, illustrated in Fig. 1, crosses the south branch of the Chicago River at Halsted Street. Its span is 130 ft., it provides for city highway and electric railway traffic, and lifts 140 ft., affording vertical clearance for boats of 155 ft.

2 In common with many later vertical-lift bridges, the Halsted Street bridge consists of a simple span between two towers. The live loads are transmitted to the piers in the ordinary manner, but the dead load is counterbalanced by a set of weights, equal in weight to

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the lift span, and connected to it by wire ropes which pass over grooved sheaves on the tops of the towers. The dead load of the span and counterweights is therefore carried to the piers entirely by the towers.

3 Unlike any bridge of this type which has succeeded it, this bridge is operated by machinery which is located under the roadway, at the base of one of the towers. Its power-transmission equipment consists of a system of wire-rope drives running from the grooved

FIG. 1 HALSTED STREET BRIDGE OVER SOUTH BRANCH OF CHICAGO RIVER, CHICAGO, ILL.

130-ft. span, 140-ft. lift. Design of J. A. L. Waddell, Kansas City, Mo.

drums in the machinery house to each end of the lift span, and to each counterweight. There are 16 ropes in all. Eight up-haul ropes, passing around a set of idlers at the bottom of the near tower, are carried to its top where they divide into two groups. Four turn downward over another set of sheaves and attach to the near end of the lift span, and four, running horizontally to the top of the far tower, are there deflected downward, and attach to the far end of the lift span. The eight down-haul ropes, in similar manner, are connected to the tops of the counterweights.

4 On account of the extreme height of these towers, some 217 ft. from the water to their tops, it was considered advisable to steady them by well-braced lattice girders, running from top to top, and these latter serve as a support for the idler sheaves placed midway between towers to guide and steady the horizontal reaches of the operating ropes.

5 This bridge is still in service and is giving satisfaction. The only material change in its operating machinery from that at first installed, was the substitution some years later of electric motors for the original steam engines. It is of interest to note that Dr. Waddell had recommended electric motors in the original design but the city had not accepted them on the ground that they were "untried toys."

6 It was not until 1909 that another vertical-lift bridge was built. The firm of Waddell & Harrington had meantime been formed and a new impetus was given to this type of structure. Late in 1908 designs were begun for a bridge across the Mississippi on the line of the Iowa Central Railroad near Keithsburg, Ill. It was decided to make one of the spans a lift span, and in the design several improvements were made on the operating mechanism of the Halsted Street bridge. Chief among these was the change in the location of the machinery from the pit below the tower to the top of the lift span. The advantages in this were several; the most important being that it shortened materially the length of operating ropes and reduced to a minimum the complications in their connection and arrangement; and it put the operator at once in reach of his machinery and in view of the river and approaching trains.

7 The scheme of operation — that used on nearly all succeeding lift spans — is as follows: The motor, in this case a gas engine, is connected by a train of gears to four spirally grooved operating drums, two over each top chord. Two operating ropes are fastened by rope clips to each of these drums, one for the upward movement of the span and the other for the downward, and are so wound on the grooves of the drum that the up-haul rope is wound on while the down-haul rope is paid off, and vice versa. An up-haul rope runs from each drum to the corresponding corner of the lift span, there over a double-grooved deflector sheave, and thence to the top of the tower, to which it is connected. The down-haul rope parallels the up-haul as far as the deflector sheave, and there, passing downward over the other groove in the latter, connects to the tower at a point in convenient reach of the deck. At each point of connection

to the tower, suitable means of adjusting the tautness of the rope is provided; in this case an ordinary eyebolt threaded its full length.

8 Rotation of the drums in one direction winds on the up-haul ropes, causing an upward force at the deflector sheaves and thus, overcoming the friction of the tower-sheave journals in their bearings, the unbalanced weight of suspended ropes and the inertia of the moving parts, lifts the span. Similarly, rotation in the opposite direction lowers the span. All four of the operating drums are locked together by the connecting gearing, thus insuring the synchronous rotation of the tower sheaves and keeping the span at all

FIG. 2 PORTION OF THE OPERATING MACHINERY, BRIDGE NO. 458, PENNSYLVANIA LINES

300-hp. railway-type motor; steel driving gears with 20-deg. involute-cut teeth, and operating drums. The large gear in the foreground has teeth of 4½ in. circular pitch; the shaft is 10 in. in diameter.

times parallel to its original position. The general scheme of operation is illustrated by Fig. 2.

9 To keep the span in proper alignment between the towers, vertical tracks are provided on the four tower legs adjacent to it, and on these tracks bear the rollers which hold the span both in transverse and longitudinal alignment. On account of temperature changes in the span length it was considered necessary to provide heavy springs to act upon the longitudinal rollers, thus holding them at all times in contact with their tracks. This design was later found to be somewhat objectionable, and was improved upon

in some later bridges. It was considered impracticable to guide the span so closely during its entire lift that when brought to seat the rails would be in proper alignment for the operation of trains, and wedge-shaped steel castings were therefore located at the foot of each tower, and arranged to engage close-fitting mating castings on the span when the latter was still 2 ft. above its seat. At one end of the span these centering castings were arranged to provide longitudinal centering also and were made heavy enough to resist, in addition, the force of a train suddenly braked on the span. At the other end transverse centering only was afforded, thus allowing for temperature changes in the length of the lift span.

10 The Keithsburg bridge has a low lift, only 40 ft., but is 229 ft. long, or 100 ft. longer than the Halsted Street span, and is half again as heavy. On account of the comparative shortness of the towers, the overhead truss was considered unnecessary. Since 1892 considerable advance has been made in attachments for wire ropes, and the new designs were used in this structure. Rope sockets of steel could now be bought which would develop the ultimate strength of the rope, and these were employed instead of the rather clumsy sets of rope clamps of the Halsted Street design.

11 One feature of the design of this bridge, continued on a number of others, although usually in modified form, is the locks. These lock automatically and not only hold the bridge down when once seated, but also hold it in case one or both ends should not be entirely seated by the down-haul ropes, a condition considered quite possible either from a lack of adjustment or unequal stretching of the latter. The lock adopted is automatic in action. It consists of two cams locked together by two segmental gears and counterweighted to swing toward each other and grip a link hanging from the lift-span floor beam. The cams are supported by a steel-casting anchor bolted to the piers, and the link in descending separates them and is in turn held by them when the end of the span is 1 in. above its final down position. Should a load come on with the end thus, the latter would be carried on down and the cams would swing further toward each other, locking it firmly in place. Unlocking is accomplished by a foot-shaped bar sliding vertically on the floor beam and connected by a wire rope to the lock lever in the operating house.

12 To save metal in the trusses of the lift span the machinery house was located on one end of the span. No difficulty was anticipated in such an arrangement, but after operation was started it was

found that the set of ropes leading to the far tower, about 100 ft. longer than those attaching to the near tower, stretched much more than the latter; and this condition caused the near end of the span to rise before the far end, and produced a halting, uneven movement throughout the lift.

13 Another lift span was almost complete when this condition was discovered, and the plans were immediately changed by moving machinery and house to the center of the span.

14 The counterweights of the Halsted Street bridge had been made of cast iron, but considerable money has been saved on the Keithsburg bridge and on all later bridges by making them of concrete. The construction usually adopted for each weight consists of two vertical steel members, one at each end of the weight, connected at the bottom by one or more laced struts and ending at the top in the equalizing devices to which the suspending ropes are attached. In this steel framework is usually cast a solid block of concrete, although several sets of weights have been built of previously cast blocks laid up in tiers on a big concrete beam at the bottom.

15 The equalizing devices referred to above consist of sets of balance bars, each set attached at its upper end to the rope sockets and terminating at the bottom in a single pin for each counterweight. The accepted form of equalizer in Fig. 3 was designed to meet a condition at the time unprecedented, i.e., 16 2¼-in. ropes receiving their load from a single pin. On the Keithsburg bridge and on several succeeding it, the equalizers had been of straight horizontal bars and vertical links, each of the former having three pins on line. This device effects a very material saving in space over the preceding form and also has the advantage of being much less seriously affected should one of the ropes break. In fact, if a side of one of the top bars should drop, the load would shift laterally and readjust itself to such an extent that the remaining 15 ropes would each get an approximately equal share of the load originally supported by the broken one. This advantage over the former type is readily seen when it is realized that to break one rope of a pair in the earlier design would cause the other to receive double its original load.

16 The third important bridge to be built was across the Willamette River at Hawthorne Avenue, Portland, Ore. The lift span is 244 ft. long and lifts 116 ft. The main points of improvement in this design over that of the Keithsburg bridge are that the machinery is on the center of the span, as above noted, and is much more com-

pact, all gears being mounted in the same frame instead of being supported on isolated bearings bolted to different parts of the steelwork. Operation is by two electric motors instead of by gas engine as on the former bridge.

17 Although the choice of power for operation is rarely within the control of the designer, but is dependent rather on local conditions, it is well to note that wherever possible to obtain it, electric power is far superior to any other, as it makes possible niceties in control, and interlocking mechanisms and safeguards not possible

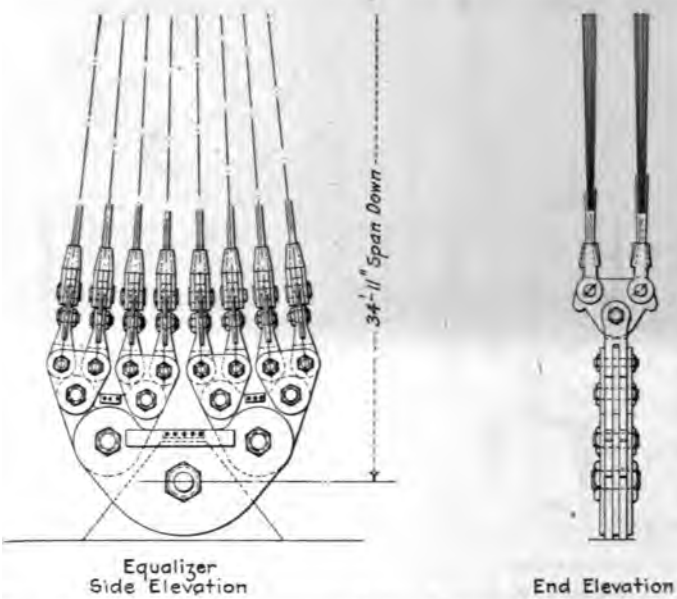

FIG. 3 EQUALIZER, WILLAMETTE RIVER BRIDGE, OREGON-WASHINGTON RAILROAD AND NAVIGATION CO.

with any other kind of power. For lift-bridge operation direct-current motors are more economical than any other because of their high starting torque in proportion to their size.

18 While the Hawthorne Avenue bridge was under construction another lift bridge of entirely different character was being designed. This was the 425-ft. span of the combined highway and railway bridge across the Missouri River at Kansas City. It consists of two decks, a fixed upper deck for highway and electric railway, and a lower deck for railway traffic, the hanger posts of the

latter telescoping into the truss posts of the former as the lifting deck rises.

19 The live load coming on each lifting-deck hanger is carried by a pin into two saddle diaphragms in the upper deck truss. The dead load is carried into a pair of suspending ropes which, passing up through the upper deck posts, over a deflector on the top chord, along the chord to the operating sheaves, and then downward over another deflector, terminate in a counterweight. There are 15 panel points for each truss, and each point, except the two in the center, has one counterweight; the center points have two each, making 32 in all. There are two operating sheaves at each end of

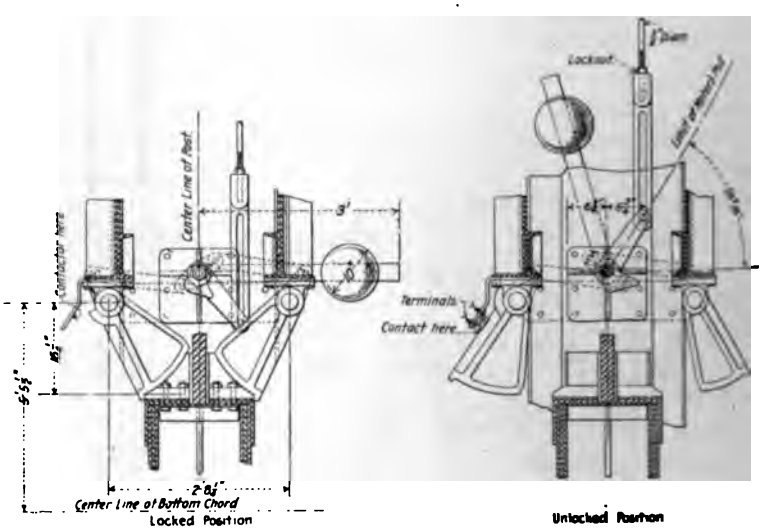

FIG. 4 LOWER-DECK AUTOMATIC CAM LOCK, WILLAMETTE RIVER BRIDGE, OREGON-WASHINGTON RAILROAD AND NAVIGATION CO.

the bridge, and each pair is controlled by a motor and gear train near it. All suspending ropes pass over the four operating sheaves and motion is transmitted to the lifting deck by virtue of the friction between the former and the latter. The two sets of machinery, one at each end, are made to act together by means of two rope drives, one acting when the span is lifting, the other when it is lowered.

20 Each intermediate panel point of the lower deck is locked down by a cam lock similar to the one later installed on the bridge of the Oregon-Washington Railroad and Navigation Co. over the Willamette River at Portland and shown in Fig. 4. This is a further

velopment of the lock for the Keithsburg bridge above described, d is fully automatic for locking.

21 Each end of the span is latched down by a lock operated by wire rope pulled by a segmental sheave in one of the machinery uses. All the hanger locks, 26 in number, and the two end locks, e operated by the same motor and gear train.

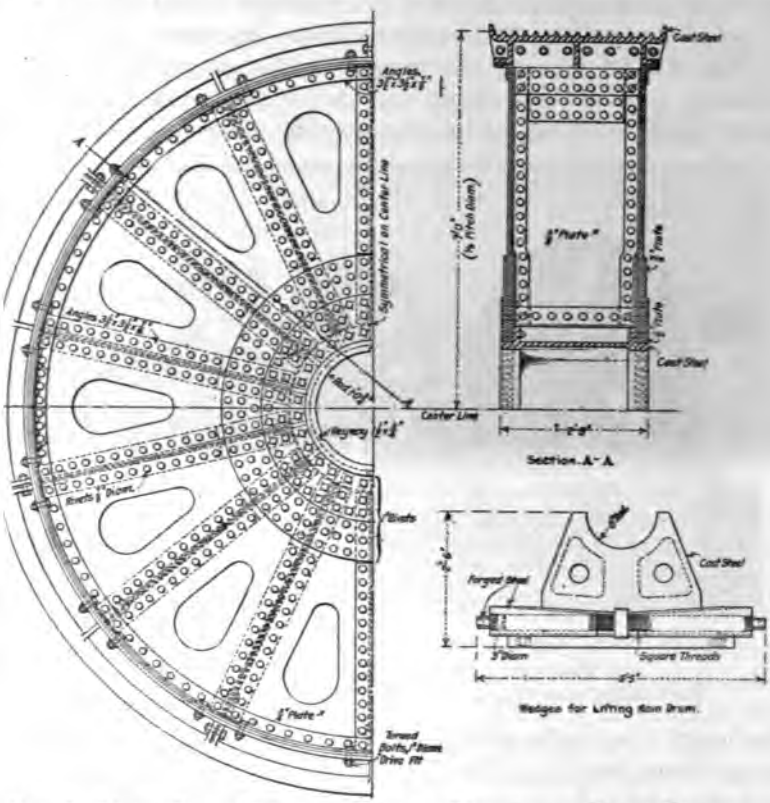

FIG. 5 14-FT. PITCH DIAMETER SHEAVE, WILLAMETTE RIVER BRIDGE, OREGON-WASHINGTON RAILROAD AND NAVIGATION CO.

22 The bridge designed for Oregon-Washington Railroad and avigation Co. across the Willamette River at Portland, Ore., s some points of interest. It is a combination of a simple lift an and the lifting deck just described. This lift span is 211 ft. ng, weighs 3,420,000 lb. and lifts 89 ft., while the lifting deck below can lift independently for 46 ft., and will then lift with the span r 89 ft. The advantage of this arrangement is evident when it

is realized that the highway traffic on the upper deck is not interrupted for ordinary river traffic, as the upper deck must lift for high-masted vessels only. There are five or six full operations daily and ten times that number of lower-deck lifts.

23 The large tower sheaves of this bridge are the first of this size and type. They are 14 ft. in pitch diameter, carry sixteen 2¼-in. ropes, and are made of cast-steel rim segments bolted on to a center of rolled-steel plates and a cast-steel hub. The sheaves are detailed in Fig. 5. An unusual requirement in the design of the sheave bearings was that they should provide for replacement of the phosphor-bronze bushings. This was considered necessary because of

FIG. 6 TWO 12-FT. CAST-STEEL SHEAVES AND SUPPORTING GIRDER OF MISSOURI RIVER BRIDGE AT MONDAK, MONT.
These sheaves weigh 7½ tons each and were built without any failures in casting.

the heavy river traffic at this point and the necessarily large number of operations required. The load on each sheave shaft is 1,768,000 lb. and the space for lifting mechanism limited. Fig. 5 shows how this requirement was met by a system of wedges; the projections on the ends of each sheave shaft are for the purpose of resting in a steel saddle casting of the wedging devices.

24 After the span had been placed in operation a rather serious difficulty was observed with these sheaves. It was noticed that when they turned, nuts and broken bolt ends began to fall, and it was found that they were coming from the flange connections of the steel rims to the angle of the supporting steel centers. Careful investigation developed that the inner circumference of the assembled

rim castings was slightly longer than the outer circumference of the steel disks on which they were designed to bear. Because of this fact the ropes forced the error to accumulate at the bottom of each sheave, separating appreciably the rims from the disks and breaking the connecting bolts. This discrepancy had not been detected until the sheaves received their load. On later designs in which this type of sheaves has been used, no reliance has been placed on the bearing of these castings on the steel disks, but the former have been made to project down between the latter and are securely riveted to them by horizontal rivets sufficient in number to carry the loads in shear.

25 The reason for making these large sheaves of built-up plates and castings is because of the difficulty of getting single steel castings of adequate size. When the Hawthorne Avenue bridge sheaves were made, and they are only 9 ft. in pitch diameter, the shop got a satisfactory set of eight castings only after having six rejected because of serious flaws. This was in 1910. That considerable improvement had been made in three years in the processes used in making large steel castings is attested to by the fact that in 1913 four sheaves 12 ft. in pitch diameter, and weighing 7½ tons each, were built without any failures in casting. These are the sheaves of the Missouri River bridge at Mondak, Montana, illustrated in Fig. 6.

26 Another trouble with some built-up tower sheaves occurred in connection with those for the three bridges of the Pennsylvania lines in Chicago. These bridges were all put into service in the winter of 1913 and the summer of 1914. The sheaves on all of them are 15 ft. in pitch diameter, and the difficulty referred to resulted from faulty shopwork in fitting the steel disk plates to the cast-steel hubs. One of the spans had been put into service before the trouble was discovered and had to be repaired between operations. The first manifestation of anything wrong was the loosening and breaking of rivets between the flanges of hub castings and the disk plates. Examination showed that the holes for the hub castings were too large and that there was a creeping going on between the disks and the hub. This was corrected by drilling holes into hubs and disks where they come together and driving in slightly tapered tool-steel pins. The scheme will be evident upon examination of Figs. 7 and 8.

27 A bridge illustrating the most recent arrangement of operating machinery is that designed for the Vladicaucase Railway for a crossing of the Don River near Rostoff, Russia. By reference to Fig. 9 it will be noted that the drums are close together instead of

being at the opposite ends of the main drive as is the case with the Pennsylvania bridge illustrated in Fig. 2. The advantage in this arrangement is one of economy. It will be noted that a large gear reduction is made at the drums and that there is only one line of shafting across the bridge instead of two. With the reduction used,

FIG. 7 REPAIRS TO HUBS OF BUILT-UP SHEAVES FOR PENNSYLVANIA LINES BRIDGES IN CHICAGO

It will be noted that the hub casting projects outward from the face of the disk plate, making necessary the guiding arrangements in Fig. 8.

FIG. 8 CAST TEMPLET AND AIR DRILL, PENNSYLVANIA LINES BRIDGES, CHICAGO

The holes for the hub casting were found to be too large. This defect was corrected by drilling holes into hubs and disks where they come together and driving in tapered steel pins.

this shaft is considerably smaller than one of the two required in former layouts. The gear frame is also much smaller. It will be noted that auxiliary power is furnished by a small gas engine operating through a gear reducer.

28 One of the heaviest bridges so far designed is that over

the South Branch of the Chicago River at Chicago, known as Bridge No. 458, Pennsylvania Lines. This bridge presents many interesting features and will be described at some length. It carries the double track of the Pennsylvania Lines across the South Branch near 19th Street and will be used by the Pennsylvania, the Chicago & Alton

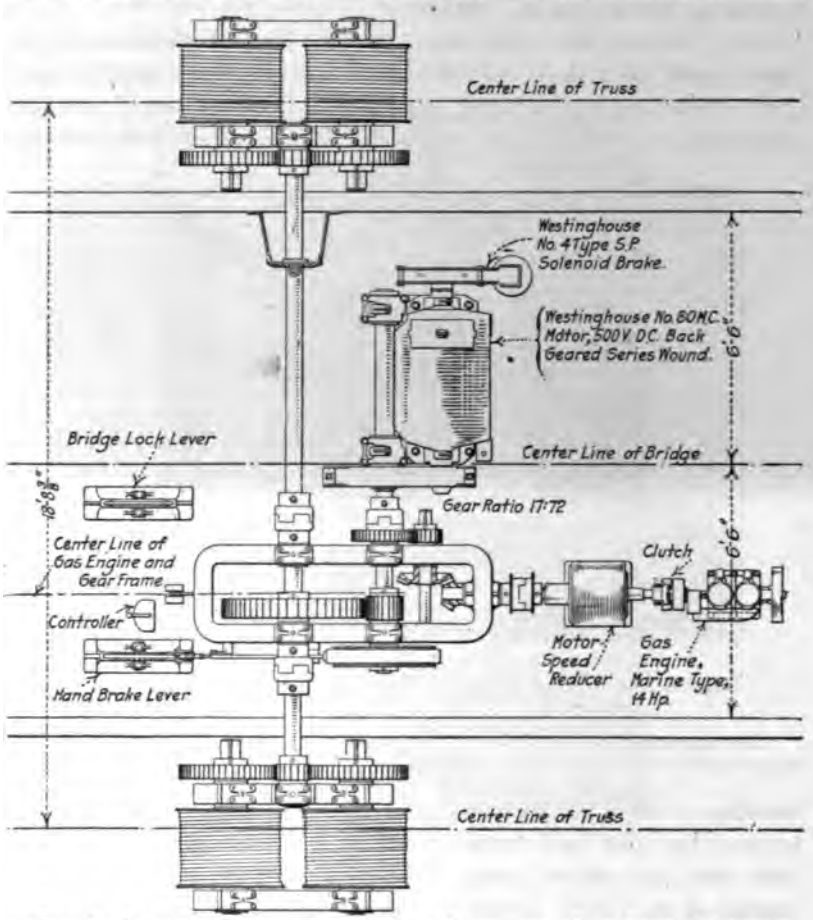

FIG. 9 ARRANGEMENT OF OPERATING MACHINERY, DON RIVER BRIDGE, VLADICAUCASE RAILWAY, ROSTOFF, RUSSIA

and the Pere Marquette. There is no *closed season* on the river at this point and the Government required that the lift span should be erected 120 ft. above the river, the normal clearance for the span when lifted. As it was not possible to drive any piling into the river bed because of the resulting obstruction to river traffic, the

falsework had to be carried entirely on the piers and spread out from each of the latter in a fan shape upward to the panel points of the trusses, as represented in Fig. 10. There were no connecting struts between the two sets of falsework and the upper end of the leaning members of each set had therefore to be tied back to the towers with steel bars and plates.

29 To erect the span with 120 ft. vertical clearance would have meant that these top chords of the falsework must in each case be attached to the tower legs halfway between two of the horizontal struts of the bracing, and as this was not considered advisable

FIG. 10 LIFT SPAN, ERECTED POSITION, BRIDGE NO. 458, PENNSYLVANIA LINES

The falsework is carried entirely on the piers and spread out from each of the latter in a fan shape upward to the panel points of the trusses.

because of the resulting bending in the tower legs, it was necessary to erect the span high enough to allow these chords to come in line with the next higher struts. This placed it at 130 ft. clearance instead of the 120 ft. required. All connections were made in holes from which the rivets had for the time being been omitted.

30 On account of the shape of the falsework the erection of this span upon it would have developed an uplift in the shoes of the far tower legs too great to be safely carried by the anchor bolts, and it was therefore decided to build the concrete counterweights in such a way that their weight would be carried into these shoes. This was done (see Fig. 11) by supporting the 800 tons of concrete

at each tower on girders which delivered the load to two inclined struts bearing on 6-in. pins carried in saddle castings riveted into the columns just above the bases.

31 There was nothing unusual in the erection of the towers, the derricks being stepped up from story to story according to practice common for similar structures. The heaviest pieces in them are the bottom sections or vertical legs next to the lift span which weigh 42 tons each. The four sheaves on the top of each

FIG. 11 COUNTERWEIGHT ON ITS FALSEWORK, BRIDGE NO. 458, PENNSYLVANIA LINES

Eight hundred tons of concrete are supported on girders which deliver the load to two inclined struts bearing on 6-in. pins carried in saddle castings.

tower weigh 31 tons each and are the largest of their kind so far built. They are 15 ft. in pitch diameter and each pair carries sixteen $2\frac{1}{4}$-in. plow-steel ropes, each weighing with its sockets about 2000 lb.

32 The span erection was carried on with two A-frame derricks shown in Fig. 10, the work progressing on the two sides simultane-

ously. Only enough falsework to carry the end panel of the span was first set from the towers, and after the erection of these panels the derricks were moved from the towers to their first positions on the span, directly above the two sway frames nearest the ends. From here more falsework and more steel was erected and the derricks were again moved out. In Fig. 10 they are shown in their third and last positions as they stood to place the steel of the four center panels.

FIG. 12 BRIDGE NO. 458, PENNSYLVANIA LINES, AFTER REMOVAL OF FALSEWORK

The old swing span was kept in service until the upper structure was completed.

To regulate the temporary camber to suit the erection of the last pieces of top chord, four hydraulic jacks were set beneath the bottom chord, immediately above the ends of the last four members of the falsework. Because of the eccentric loading on the towers there was bound to be some deflection of each tower toward the river, but calculations and measurements had been so carefully made that the two center pieces of bottom chord, 73 ft. 6 in. in length and

weighing 36 tons each, when lowered into place fitted so exactly that the erection bolts could be entered without the use of drift pins. To get the last pieces of top chord in it was necessary to use the jacks.

33 Fig. 12 shows the bridge after the removal of the falsework and while the old swing span was still in service. This latter was partly under the new bridge, both open and closed, and as more than 300 trains use this crossing every day it was very important to take great care that nothing should be dropped from the span 100 ft.

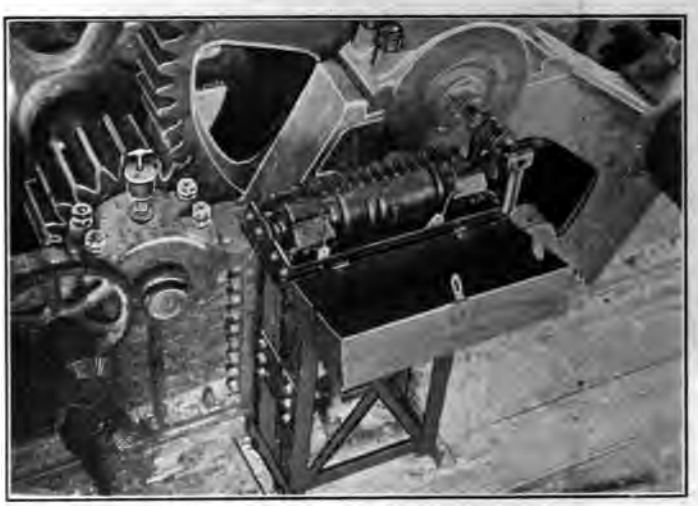

FIG. 13 ELECTRICAL INDICATOR AND LIMIT SWITCH, BRIDGE NO. 458, PENNSYLVANIA LINES

This apparatus indicates by lights in the operator's house several points in the height traveled by the span, and cuts the controller circuit near each limit of travel.

above. It is a matter for which the erecting contractor deserves congratulation that no accidents from this source occurred.

34 The new span is 272 ft. 9½ in. long, lifts 112 ft., and weighs 1600 tons. At present it will be lifted at the rate of 15,000 times a year, for it lies near enough to the water to be in the way of every tug, but the great majority of these operations will require lifts of only a few feet. In a few years' time it is planned to raise the grade at this crossing, and the design of the bridge was carried out with this idea in view. Aside from raising the floor systems in the towers, lowering one story of tower bracings and raising the base castings of the lift-span shoes, no change in this bridge will be necessary to

accomplish this end. The span is operated by two 300-hp. series motors drawing their power from a 120-cell storage battery.

35 The electrical indicator and limit switch in Fig. 13 is connected to the drive by worm-gear reduction, indicates by lights in the operator's house several points in the height traveled by the span, and cuts the controller circuit near each limit of travel, thereby breaking the

FIG. 14 EQUALIZER AND COUNTERWEIGHT, ERECTED POSITION, BRIDGE NO. 458, PENNSYLVANIA LINES

When the span is lowered into place the parts of the equalizer become more closely packed together. An outer view of this equalizer is shown in Fig. 11.

main circuit, stopping the motors, and applying the solenoid brakes. Details of the equalizer and counterweight are shown in Fig. 14. Waddell & Harrington were the designers, represented in the field by the writer, and the Pennsylvania Steel Company were the contractors for fabrication and erection of superstructure.

DISCUSSION

J. A. L. WADDELL[1] (written). Mr. Van Cleve's excellent paper has proved of special interest to the writer, who may justly claim to be the father of the modern vertical-lift bridge. His first design, made in 1892, was for a 250-ft. span at Duluth, Minn., to cross the canal which forms the entrance to the harbor of refuge for lake vessels in that vicinity. The War Department prevented the building of the structure, but in 1902 permitted at the same location the construction of a *transbordeur*.

Soon after the rejection of his plans for that proposed bridge, the writer was retained to design and supervise the construction of a similar but shorter-span bridge at South Halsted Street, Chicago, the first bridge mentioned in the paper. This structure was built under great difficulties and in spite of many discouragements. The Chicago engineers as a body were opposed to this type of bridge; and the then highest authority on bridges in America, the late George S. Morison, stated flatly that it could not possibly operate, and that it would be impracticable to raise the span off the piers. On the strength of this statement the City Engineer made all the arrangements for canceling the contract for the construction although some of the substructure had been completed and a large portion of the metal work had been manufactured. It took some very earnest pleading by the writer to persuade him to permit the work to proceed; and the said pleading would not have been successful had it not been for an important fact pointed out, viz., that the city of Chicago would have had to pay the full contract price for the structure whether it were built or not.

The specifications called for the lifting of the span to the full height (involving a raise of 140 ft.) in 60 sec.; and, much to the surprise of everybody, on the first trial the span went up in about half of that time. Afterward the writer timed the operation, both up and down, and found that the span could be moved over the full height in 28 sec. This was certainly a great triumph for a comparatively young engineer in a struggle with the local technical body, including the highest bridge authority in America.

Referring to the Keithsburg bridge which Mr. Van Cleve mentions, the heavy-duty, slow-speed gasoline engine used is clumsy,

[1] Of Waddell & Son, Inc., Consulting Engineers, Kansas City, Mo., and New York.

FIG. 15 DOUBLE-TRACK LIFT BRIDGE OF PENNSYLVANIA LINES AT LOUISVILLE, KY.

ponderous, and conducive to jar, although undoubtedly effective. It is quite certain that a light, high-speed type, such as the automobile or tractor engine, will prove more satisfactory for future lift bridges.

In truth, though, gasoline engines are to be used for lift bridges only as a last resort or as an auxiliary; because electric motors are far superior in every respect. Again, direct-current motors are much more satisfactory than alternating-current motors and, consequently, they should be used whenever an ample direct-current supply of power is obtainable.

Mr. Van Cleve mentions that the heaviest sheaves yet used for any vertical-lift bridge were those for Bridge No. 458 of the Pennsylvania Lines West of Pittsburgh, and that each sheave weighs 31 tons. Within the last few weeks there has been completed for the same railway company a vertical-lift bridge, designed by Waddell & Son, Inc., across the Louisville and Portland Canal that lies adjacent to the Ohio River at Louisville, Kentucky; and the sheaves for this structure weigh 38 tons each.

As this is the very latest thing in lift-bridge construction, the following description of the structure should prove of interest:

The double-track span, which is 260 ft. long between centers of end bearings, weighs about 3,000,000 lb., and is lifted 32.4 ft. in 45 sec. There are 64 counterweight ropes $2\frac{1}{8}$ in. in diameter, passing over the four 15-ft. sheaves. The motive power consists of two 150-hp., 220-volt, alternating current, 60-cycle, 580-r.p.m. motors equipped with solenoid brakes. Magnetic control is used. Speed reduction from the motors to the winding drums is made through a train of three sets of spur gears to a cross-shaft having a pinion at each end meshing with two drum gears.

The span is shown complete in Fig. 15. The operating drums which raise or lower the span are quite similar to those used in the Don River bridge in Russia. However, the detail of the cross-shaft has been improved by adding two bearings and two couplings, thus giving more rigid supports for the pinions and making the lengths of shaft between the center main frame and the drum frames truly flexible. This detail eliminates entirely any trouble from errors in the alignment of the three frames, which otherwise would cause considerable friction and loss of power. Hand operation is provided for by two 4-arm capstans.

There are 16 plow-steel operating ropes, each 1 in. in diameter, the drums and sheaves over which they run being 36 in. in diameter.

These ropes work in pairs, i.e., there are two up-haul and two down-haul ropes at each corner of the span. The take-up devices for the ropes are eyebolts threaded over the entire length, with anchorage attachments at top and bottom of towers.

The counterweight sheaves, the heaviest yet built, are constructed of steel plates, angles and castings. In their designing special care was taken to eliminate the troubles which had arisen in connection with the built-up sheaves described in Mr. Van Cleve's paper. Each rim segment is fastened to the side plates by a sufficient number of rivets to take the entire load coming upon it from the ropes; and ½-in. spaces were left between the segments so that there might be no trouble if the lengths of the segments should overrun. It was originally intended to fill these spaces with hemp; but the cutting tools gave trouble when the machining of the grooves was begun; and it was found necessary to fill them with babbitt. The trouble previously experienced from bad fit of side plates on the hub casting was eliminated by making the said side plates bear directly on the shaft instead of on the hub casting. The hole for the shaft was bored out after the sheave was completely assembled and riveted. The journals are 22½ in. in diameter and 24 in. long, the overall length of the shaft being 7 ft. 8 in. The hub is keyed to the shaft by three keys 1½ in. wide and 1 in. deep, secured from longitudinal movement by set screws. The bearings are lined with phosphor-bronze bushings for high pressure and low speed. Oil grooves are cut into the bushings, the lubricant being supplied from marine-type, screw-feed, compression grease cups.

The rail locks are of sliding-tongue type, standard with the Pennsylvania Lines. The four tongues at each end of the span are driven by a 5-hp. motor. Limit switches are provided to cut off the current at each end of the travel. The controllers for the rail-lock motors are interlocked with the signal system so that the locks cannot be opened until the signals are set against train movements over the bridge, and so that clear signals for train operation cannot be given until the locks are closed. The controllers are also interlocked with those for the main operating motors so that current cannot be supplied to the latter until the locks have been opened, and so that the locks cannot be closed until the bridge has been seated.

The span is kept in correct position during motion by guide rollers, which roll on vertical guides on the outsides of the tower columns. There are eight rollers for transverse guiding, one at

each L_0 point and one at each U_0 point. Longitudinal guiding is effected by two rollers at each L_0 point at the fixed end of the span. There is considerable play in the guides so as to eliminate any possibility of binding. On account of this play they do not center the span closely enough for the rail locks, which have very little play. For this reason there is placed a transverse centering casting, having very little play, at the middle of each end floor beam. In earlier designs a transverse centering casting was placed at each L_0 point; but considerable play had to be left in these castings to provide for expansion and contraction, and they did not center the span accurately enough for the rail locks.

The train thrust is cared for by two thrust castings, one at each L_0 point at the fixed end of the span.

In order to eliminate jar when the span seats, there are provided air buffers near each end of each of the end floor beams. Adjustable needle valves on the exhaust ports of the buffers enable the resistance of the said buffers to be varied at will.

Bridge locks were not used, but the counterweights were made about six tons lighter than the span, the excess weight of the latter overcoming any tendency for it to rise.

The span can be handled from the machinery house, which is located at the center thereof, or from an interlocking tower on shore about 100 ft. from the south end of the span. It is intended to operate the span from the machinery house until the operators become thoroughly familiar with the manipulation, after which it will be operated from the interlocking tower. Duplicate switchboards, with indicator lamps, meters, etc., are placed in each house. The main switchboards and the resistances are located in the machinery house.

As was stated previously, each motor is equipped with a solenoid brake. In addition there are two other brakes, one operated by hand and the other by motor. The lever of the hand brake is in the machinery house on the span, and gives the operator graduated braking power, so that he can stop the moving mass without jar. The controller of the motor-operated brake, which has three degrees of braking power, is located in the interlocking tower. These braking devices are not of great importance in a slow-moving bridge like this one; but for a high-speed bridge, which will coast for several feet after the current has been turned off, they are much more important.

The erection of the lift span was quite difficult, as traffic had to

be maintained over the bridge and as navigation could not be interfered with. The old moving span was a swing. It was at first proposed to erect the new span in its fully lifted position. As the counterweights would then have to be built at the lowest point of their travel, it would have been necessary to leave large notches in them for the passage of trains. This scheme was abandoned for that and other reasons, and a new one was worked out. Permission was secured from the United States Government to leave only a 100-ft. channel near the north tower. This channel was spanned by a plate-girder lift span of the same type as the main span, worked by hand-operated crabs. After the main-lift-span towers were partly erected, navigation was stopped for a few hours while one end of the swing span was removed, the gallows frames for the plate-girder-span towers were erected, and the plate-girder span placed in position. The remainder of the swing span was then removed, the towers erected, the sheaves and ropes placed thereon, and the counterweights constructed on falsework resting on the piers and floor beams. The south portion of the lift span was then erected, also the north hangers; and the counterweight ropes were attached. The machinery was erected complete and thoroughly tested out. Navigation was then closed for a day, the plate-girder span removed, the remainder of the lift span erected and riveted, and the operating ropes connected up.

Special care was taken in the aligning of the main-sheave bearings. This was done by means of a steel straight-edge as long as the shaft. The bushings had been scraped to fit the shafts in the shop, the shafts and bushings being matchmarked. The alignment was so carefully done that when the sheaves were hoisted up they fitted perfectly in the bearings, and each 38-ton sheave could be rotated by one man. The machinery and motors were also aligned and tested out very carefully. The motors were run for several hours before the operating ropes were attached to the drums, in order to get the machinery into smooth-running condition and to determine if there were any poorly aligned bearings. Any hot bearings which developed were realigned. The machinery and the electrical equipment were in perfect operating condition before the operating ropes were attached to the drums and before the plate-girder swing span was removed.

Waddell & Son, Inc., have lately designed deflection bearings for main sheaves which insure a uniform pressure over the entire length of the journal. With the high bearing pressure used in the design

of journals for lift-bridge sheaves and bascule trunnions this is extremely advisable. The use of this type of support greatly simplifies the problem of aligning the bearings.

One general fault of the electric equipment of movable bridges may be pointed out — that of using too small power lines. The overload capacity of the motors for vertical-lift bridges is called into play if a span becomes unbalanced, and, for bascules, when operating against a high wind; and this requires power lines of ample capacity. This point is not quite so serious in the case of direct-current motors, as the drop in voltage in the power line will merely cause the motors to run slower; but with alternating-current motors the drop in voltage reduces the torque materially, because the torque of such a motor varies as the square of the voltage. For instance, a 10 per cent drop in voltage means nearly a 20 per cent drop in torque. This point requires special attention when the power lines are long.

In spite of all the opposition which the vertical-lift type of movable bridge has encountered in the last quarter of a century (some of it being very bitter and most of it totally unfair), that type has come to stay; and it will be used more and more in the future, after railroad and city officials overcome their prejudice against the use of wire rope and learn that, for economy in first cost, simplicity of design, quickness of operation, rigidity under load, and economy in maintenance and repairs, it is unequaled by any other type yet evolved.

L. S. Randolph (written). A bridge of the type described in the paper comes in the category of a piece of machinery and the question which arises in the mind of the mechanical engineer is, What is the economic problem and how does this type of bridge compare with the rolling-lift bridge?

Of the three types of removable bridge, the ordinary drawbridge revolving about a central pier limits the horizontal element of the cross-section of the waterway so that a vessel which can pass along the river cannot necessarily go through the bridge. The rolling-lift bridge limits neither horizontal nor vertical dimensions of the fairway. The vertical-lift bridge limits the vertical dimension.

While it may be answered that it is inconceivable that ships should develop to such an extent as to be inconvenienced by a height of 120 ft., such reasoning has too often been found fallacious.

It would add the final perfecting touch to a most excellent paper

uniform pitch or lay into what is technically known as a strand. A number of strands, usually six, when twisted together around a hemp or wire center form a wire rope.

3 The object of twisting the wires into strands and strands into rope is twofold: first, to bind the wires compactly together, and second, to increase the flexibility of the wire rope.

4 Another factor of great importance in rope construction is that both the wires composing the strands and the strands composing the rope shall be twisted and laid up so that there is no torsion in either the wires or strands. This lack of torsion is provided for by suitably designed machinery, so we may consider this as an accomplished fact in modern rope manufacture. Unless this were done, wire ropes would be twisty, kinky, and exceedingly difficult to handle, if indeed they could be used at all in many places.

5 These factors are mentioned at this time so as to make perfectly clear the main fundamental principles upon which wire ropes are constructed so that a better understanding may be had of the action of the stresses to which wire ropes may be subjected in various classes of service.

6 The consideration of twisting into strands and ropes brings us to a consideration of the strength of strands and ropes and how these may be determined.

7 While stranding increases flexibility, it is not accomplished without some loss in strength due to twisting, which will be explained later. It is obvious for comparative purposes that the strength of a straight wire may be taken as unity or 100 per cent. Strands are usually made of 7, 19, 37, 61, etc., wires and ropes of six strands (occasionally eight). When a number of wires are twisted together around a central wire, they make an angle with the central wire or axis. The shorter the twist the greater the flexibility, but at the same time the strength is decreased proportionately. This will be understood from Fig. 1.

8 A wire with a strength S in a strand will have a component strength T along the axis of the strand, or

$$T = S \cos \theta$$

where

$$\theta = \text{angle of helix of wire in the strand.}$$

Also, if

D_p = pitch diameter of strand
n = lay divided by pitch diameter of wires

d = diameter of wire in strand (assuming all wires the same size)
c = constant by which wire diameter is multiplied to produce pitch diameter

Pitch circumference = πcd, and Lay = nD_p . . . [1]

9 In the case of a seven-wire strand, the center wire being traight, the total strength of strand W_s is obviously

$$W_s = S + 6\,S\cos\theta = S\,(1 + 6\cos\theta). \quad . \quad . \quad . \quad . \quad [2]$$

10 If θ_1, θ_2, θ_3, etc., represent the angle of the helix of successive ıyers of wires in a symmetrical concentric strand for layers of 12, 8, 24, etc., wires,

$$W_s = S + 6\cos\theta + 12\,S\cos\theta_1 + 18\,S\cos\theta_2 + 24\,S\cos\theta_3 + \text{etc.},$$
$$= S\,(1 + 6\cos\theta + 12\cos\theta_1 + 18\cos\theta_2 + 24\cos\theta_3 + \text{etc.}) \quad [3]$$

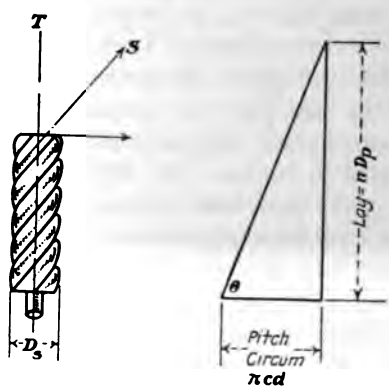

FIG. 1 TO ILLUSTRATE RELATION OF STRENGTH TO TWIST OF STRANDS

11 If the angles θ, θ_1, θ_2, etc., are equal the equation becomes

$$W = s\,[1 + (N - 1)\cos\theta] \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

vhere N = number of wires in strand.

12 Similarly in a rope:

Let W_R = strength of rope with hemp center
Y = angle of strands in rope (assuming 1 layer of strands such as 6 or 8)
N_1 = number of strands in rope.

:he strand strength W_s must be applied in just the same manner as ıefore, and

$$W_R = W_s N_1 \cos Y$$
$$= SN_1 \cos Y\,[1 + (N - 1)\cos\theta]. \quad . \quad . \quad . \quad . \quad [6]$$

ſ all wires are twisted with equal angles.

Let W = load to be lifted
w = weight of rope per foot
l = length of rope suspended vertically
L = total load or tension.

Then

$$L = W + wl.$$

INCLINES

20 For an inclined lift the Formula [1] will be modified somewhat as follows (see Fig. 2):

Let λ = angle of incline
P = pull due to load $W + wl$
F = friction factor, which is a function of $(W + wl)$ and the angle of the incline λ
$P = (W + wl) F \sin \lambda$.

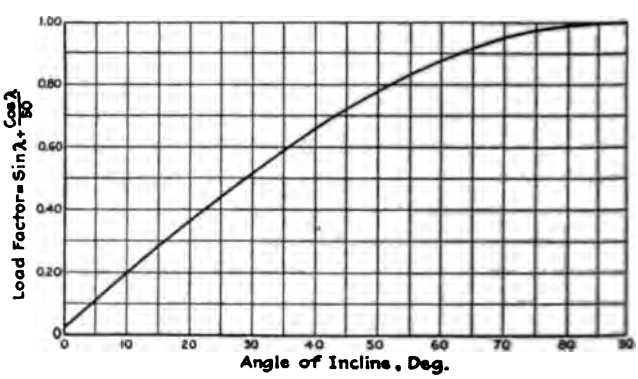

FIG. 3 LOAD FACTORS FOR DIFFERENT DEGREES ON INCLINED PLANES

21 The friction F of the cars on the incline operates normal to the line ab and is therefore a function of $\cos \lambda$. The maximum value is when $\cos \lambda = 1$ or on a level track and the minimum for $\cos \lambda = 0$ when $\lambda = 90$ deg. Starting friction being the greatest, this alone need be considered. Assuming a value of 2 per cent,

$$F = \frac{(W + wl) \cos \lambda}{50} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [7]$$

Therefore

$$P = (W + wl) \left(\sin \lambda + \frac{\cos \lambda}{50} \right). \quad . \quad . \quad . \quad . \quad . \quad [8]$$

Values for the load factor $\left(\sin \lambda + \frac{\cos \lambda}{50}\right)$ for values of λ from 0 to 90 deg. are given in Fig. 3.

MOVING TENSION — ACCELERATION AND RETARDATION

22 In the case of very slow-moving ropes, the rope stress in any straight portion will be equal to the load being lifted in the case of a vertical hoist or, on an incline, the tension due to the angle of incline, but there are many cases where rapidly moving ropes are subject to heavy stresses of acceleration or retardation where the factor of safety under static load is reduced very much by quick stops and starts. The value of the stress due to acceleration may be calculated thus:

Let T = time of acceleration
W = weight to be lifted, lb.
w = weight of rope per ft., lb.
E_r = modulus of elasticity of rope
a = acceleration or retardation of load, ft. per sec. per sec.
S = space in which acceleration or retardation is made
V = velocity of load, ft. per sec.
K = kinetic energy of the moving load
k = kinetic energy of the moving rope

$$K_t = K + k = C\,(W + wl) \quad . \quad . \quad . \quad . \quad . \quad [9]$$

where C is a constant by which the load is increased due to kinetic energy, and a factor representing the increase of the total load. Therefore,

$$K_t = \frac{WV^2 + wlV^2}{2g} = \frac{V^2}{2g}(W + wl). \quad . \quad [10]$$

but as

$$V^2 = 2\,aS$$

$$C\,(W + wl) = \frac{aS}{g}(W + wl) \text{ or } a = \frac{Cg}{S}. \quad . \quad . \quad . \quad [11]$$

Also

$$a^2t^2 = 2\,gC$$

and if

$$t = 1,$$

$$a = \sqrt[2]{2\,gC} = 8.02\,\sqrt[2]{C}.$$

23 Table 1 shows the effect of the acceleration on the quiet or static safety factor. An acceleration of 8.02 ft. per sec. per sec. corresponding to lifting a load 4.01 ft. per sec. from rest will reduce

results as the Reuleaux formula, to which reference has just been made. This formula is:

$$k = \frac{Ea}{2.06\frac{R}{d} + C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [12]$$

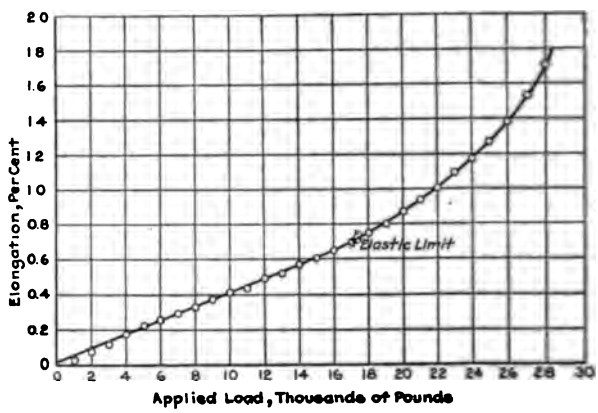

FIG. 4 TEST NO. 3: ¾-IN. — 6 x 7 ROPE; ULTIMATE STRENGTH 31,000 LB.; AREA OF WIRES = 0.213 SQ. IN.; MODULUS OF ELASTICITY = 11,922,635 LB.

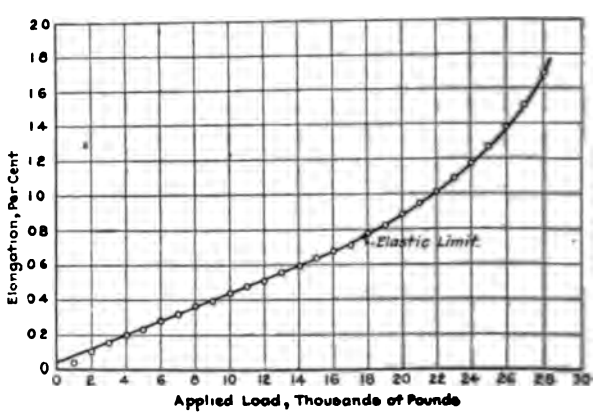

FIG. 5 TEST NO. 4: ¾-IN. — 6 x 7 ROPE; ULTIMATE STRENGTH = 32,840 LB.; AREA OF WIRES = 0.213 SQ. IN.; MODULUS OF ELASTICITY = 11,922,635 LB.

in which k = bending stress, lb.
E = modulus of elasticity of steel, taken at 28,500,000
a = area of all wires in the rope, sq. in.
R = radius of bend, in.
d = diameter of wire, in.

C = constant depending on number of wires in strand = 9.27 for 6 x 7 rope and 15.45 for 6 x 19 rope.

Substituting these values of C in [12]

$$k = \frac{0.97\,Ed}{D + 9\,d} \text{ for 6 x 7 rope} \quad . \quad . \quad . \quad . \quad . \quad [13]$$

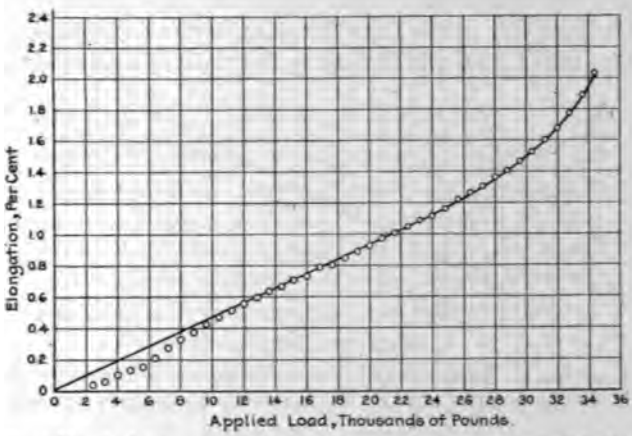

FIG. 6 TEST NO. 1: ¾-IN. — 6 x 19 ROPE; ULTIMATE STRENGTH 38,110 LB.; AREA OF WIRES = 0.2288 SQ. IN.; MODULUS OF ELASTICITY = 9,481,132 LB.

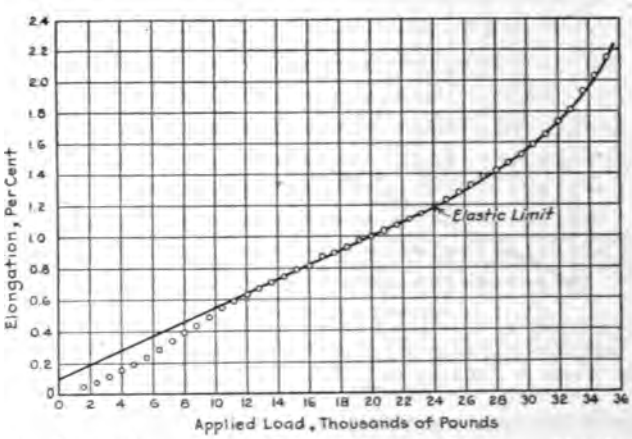

FIG. 7 TEST NO. 2: ¾-IN. — 6 x 19 ROPE; ULTIMATE STRENGTH 38,060 LB.; AREA OF WIRES = 0.2288 SQ. IN.; MODULUS OF ELASTICITY = 9,757,281 LB.

and

$$k = \frac{0.97\,Ed}{D + 15\,d} \text{ for 6 x 19 rope.} \quad . \quad . \quad . \quad . \quad [14]$$

The values for bending stress are thus about three per cent less than by the Reuleaux formula.

29 All of the preceding formulæ by Reuleaux, Rankine, Unwin and Hewitt give values much larger than the actual values because the most vital and important factor of the entire problem has been

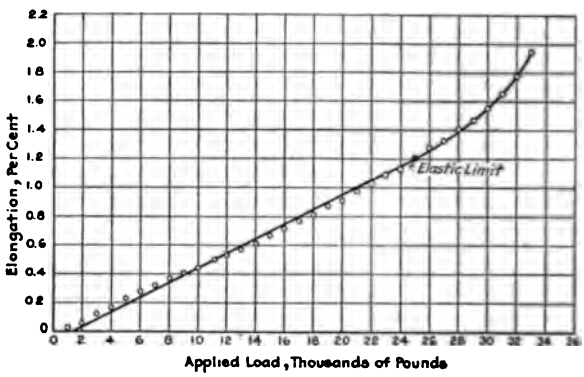

FIG. 8 TEST NO. 7: ¾-IN. — 6 x 37 ROPE; ULTIMATE STRENGTH = 36,340 LB.; AREA OF WIRES = 0.204 SQ. IN.; MODULUS OF ELASTICITY = 9,803,821 LB.

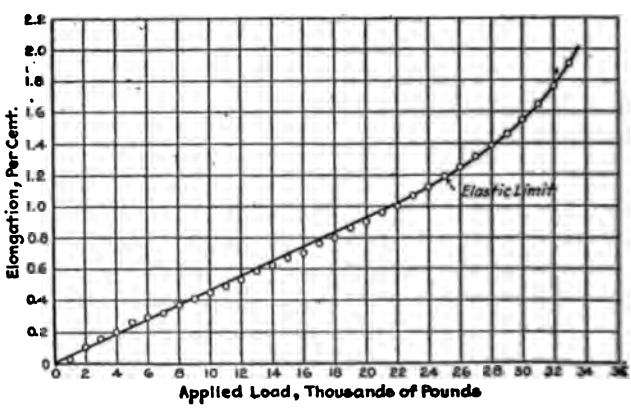

FIG. 9 TEST NO. 8: ¾-IN. — 6 x 37 ROPE; ULTIMATE STRENGTH = 37,570 LB.; AREA OF WIRES = 0.204 SQ. IN.; MODULUS OF ELASTICITY = 10,504,200 LB.

neglected. Wire ropes are manufactured not from *straight wires* but from *twisted wires*. The values obtained by the Reuleaux and other similar formulæ are correct, therefore, only for ropes composed of straight wires. That being the case, they are decidedly incorrect as applied to modern rope which is made of *twisted* wires. When these formulæ were developed there were no experimental data available

to check the results obtained, so it is not surprising perhaps that these formulæ backed by such names as Reuleaux and others have gained credence among engineers. In very similar manner the strength of ropes for many years was calculated as the aggregate strength of all the wires. Experimental data showed this conception to be wrong, as has already been explained.

30 No check tests had been made to determine the modulus of elasticity of complete wire ropes. Owing to the twisting of wires to form wire ropes the modulus of elasticity of a wire rope is much less

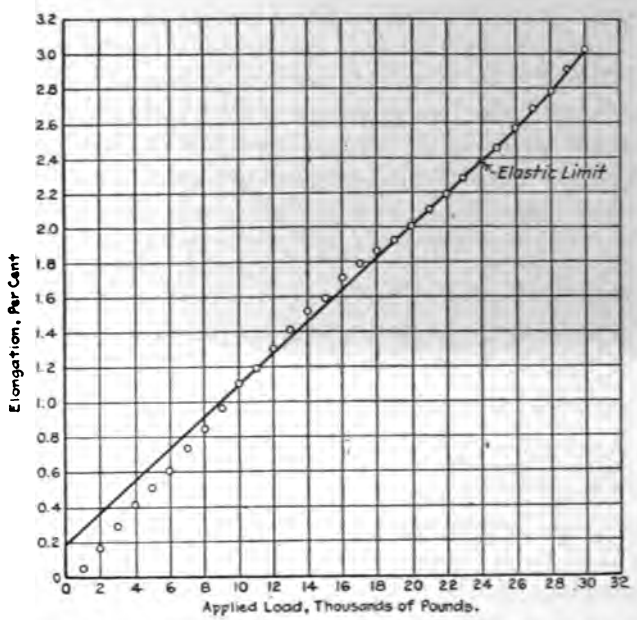

FIG. 10 TEST NO. 5: ¾-IN. — 8 x 19 ROPE; ULTIMATE STRENGTH = 34,200 LB.; AREA OF WIRES = 0.2081 SQ. IN.; MODULUS OF ELASTICITY = 5,265,800 LB.

than that of a solid bar. In order to show this graphically, curves are shown in Figs. 4 to 11, of the modulus of elasticity of 6 x 7, 6 x 19, 6 x 37 and 8 x 19 rope with hemp centers. Many other tests on similar ropes have proved conclusively that the modulus of elasticity of six-strand ropes will not run over 12,000,000 lb. and may be somewhat lower. In making such tests it must always be borne in mind that readings of elongation under light load are not as reliable — owing to the yielding nature of hemp core — as the values obtained under heavier loads. The values of the modulus of elasticity should

be taken between the points where the stress-strain diagram is approximately a straight line.

31 Herein lies the crux of the whole problem; having determined the true value of the modulus of elasticity of a wire rope, we may now proceed to the determination of the bending stress in a wire rope. Considering the Reuleaux formula, $S = Ed/D$, if we replace

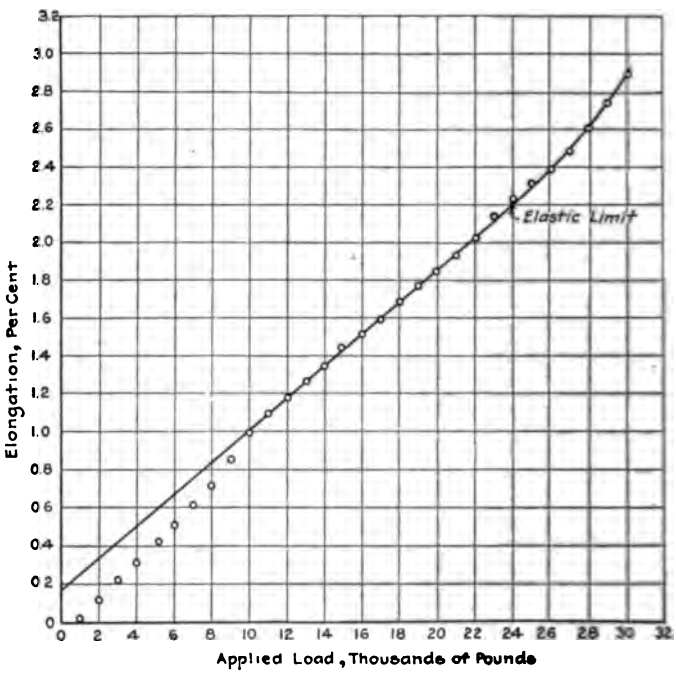

FIG. 11 TEST NO. 6: ¾-IN. — 8 x 19 ROPE; ULTIMATE STRENGTH = 34,220 LB.; AREA OF WIRES = 0.2081 SQ. IN.; MODULUS OF ELASTICITY = 5,756,700 LB.

E, the modulus of elasticity of a solid bar, with E_R, the modulus of elasticity of the rope as a whole, the formula becomes

$$S = E_R \frac{d}{D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [15]$$

which is the true bending-stress formula for a wire rope.

32 It should be specially noted that the value of S obtained is the stress per square inch of the greatest strained fiber, since it is the stress in the greatest strained fiber that determines the effect of the bending, just as it does in a beam under load.

33 If we take the value of S and multiply it by the area of the

wires in the rope, we obtain the actual bending stress in pounds. The interpretation of this value of the bending stress is important. The bending stress thus calculated shows the value equivalent to a direct tension on the rope. In other words, if the bending stress on a $\frac{3}{4}$-in. 6 x 19 rope on a 30-in. sheave is 3200 lb., the rope is subjected to the same stress as if it was under a direct tension of 3200 lb. The average value stress in the wires is, of course, one-half this amount, but it is the stress in the greatest strained fiber that determines the life of the rope. Values of bending stresses for various sizes of ropes and different sizes of sheaves are given in Tables 6 to 11, inclusive.

34 Others have endeavored to obtain these values experimentally but the results obtained have shown the bending stress to be almost negligible. Here, however, an error has crept in. *Bending stress has been confused with the effect of bending or the loss of strength due to bending* — two entirely different factors. The effect of bending obtained by this latter method has been done by passing a wire rope around a sheave and fastening the two ends and testing it to destruction. The result obtained is less than the strength of two ropes due to passing rope around sheave.

FIG. 12 METHOD OF TESTING ROPE BENT AROUND SHEAVES

35 Experiments made with a $\frac{3}{4}$-in. 6 x 19 crucible-steel rope, both ends of which were attached to sockets and the central portion of the rope passed around a 6-in. sheave, gave a breaking load in testing machine of 64,000 lb. which divided by two makes a strength of 32,000 lb. A piece from the same rope, both ends attached to sockets, gave a breaking strength of 35,000 lb. or 3000 lb. more than the bent rope. In the case of the rope bent around the sheave, the specimen broke in every case at or near where the bend took place, indicating clearly that there is a loss of strength due to bending a rope around a sheave of small diameter, in this case amounting to 8.7 per cent. A large series of tests of ropes of different constructions, sizes ranging from $\frac{1}{2}$ in. to $\frac{7}{8}$ in. in diameter, were tested some years ago in an endeavor to determine the best method of fastening wire ropes for tests. Two drums about 28 in. in diameter were mounted in an Emery testing machine and the two ends of rope passed around each drum three or four times and then clamped as shown in Fig. 12.

In every case the breaks in the rope occurred just at the point of

bend. The same ropes with sockets attached showed higher strength but the difference was not as great as in the case of the $\frac{3}{4}$-in. rope tested over 6-in. sheaves. Such experiments as these, however, do not give the value of the bending stress; they show the loss of strength due to bending.

36 Calculations may be made which show that over very small sheaves the bending stress by formula $S = E_R d/D$ gives a value greater than the strength per square inch of the material used in making wire rope. This shows that the elastic limit of the fibers of the steel has been exceeded and the rope has taken a permanent set.

37 It will be found convenient sometimes when experimental data are not available to have a method at hand for calculating the modulus of elasticity of a wire rope, since if that is known the bending stress may be determined for any construction by substitutions in Formula [12].

38 The writer in 1904 developed the formulæ given below for determining the modulus of elasticity of both strands and rope, which checks up with values obtained from a large number of experiments.

39 Considering first a strand, let E_s be the modulus of elasticity of a strand. Then E_s may be considered as a function of E, or

$$E_s = fE$$

40 Considering the first concentric strands composed of successive layers of strands, the modulus of elasticity may be determined by considering each layer of wires separately.

Let n = number of wires twisted together in one layer
nd = approximate circumference of pitch circle if the wires are laid straight (n should be in excess of 6)
d = diameter of individual wires composing the ring.

Then $\frac{\pi d}{\sin \alpha}$ = exact circumference of pitch circle (wires laid straight)
where α = angle subtended at the center of the ring by the radius of a single wire.

Also, let D_s = outside diameter of circular ring under consideration. By trigonometry,

$$D_s = Cd$$

where C is an angular function depending upon the number of wires composing the circular ring.

$\frac{d}{\cos \theta}$ = the elongated diameter of the wires normal to the axis of the strand in the twisted arrangement

where θ is the angle of wire relative to the axis of the strand, i.e., the developed angle of the helix formed by the twisted wire.

By trigonometry $\frac{\pi d}{\sin\alpha\cos\theta}$ = circumference of the pitch circle of the annular ring of twisted wires under consideration.

Let E_1 = modulus of elasticity of the annular ring of twisted wires.

Since

$$E_1 = fE$$

f = is most nearly represented by the value

$$f = \cos\theta\sqrt[2]{\frac{D_e\sin\alpha\cos\theta}{\pi d}} = \cos\theta\sqrt[2]{\frac{C\sin\alpha\cos\theta}{\pi}}$$

since $D_e = Cd$. Therefore

$$E_1 = E\cos\theta\sqrt[2]{\frac{C\sin\alpha\cos\theta}{\pi}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [16]$$

If $\theta = 0$, then $\alpha = 90$ deg. and $E_1 = E$.

41 Considering the quantity outside the radical, as θ grows smaller $\cos\theta$ approaches unity as a limit, hence at the limit $\theta = 0$

$$E\cos\theta = E$$

42 Considering the quantity under the radical with $\theta = 0$,

$$\frac{C\sin\alpha}{\pi} = 1 \quad \text{or} \quad C = \pi$$

and Formula [16] may be written approximately as

$$E = E\cos\theta\sqrt[2]{\frac{D_e}{nd}}$$

43 Having determined the value of E_1 for one layer of wires, the value E_s for a strand of any number of layers or wires may be determined as follows:

44 Let E_1, E_2, E_3, etc., equal the moduli of the various circular rings as determined by Formula [16], n_1, n_2, n_3, etc., the number of wires in the corresponding successive rings or layers, and E_s the modulus of elasticity of strand. The effect of various moduli upon the modulus of the strand as a whole will be determined by the number of wires and also by the modulus of the corresponding layer. Dividing this amount by the sum of the number of wires,

$$E_s = \frac{E_1n + E_2n_2 + E_3n_3 + \text{etc.}}{n_1 + n_2 + n_3 + \text{etc.}} \quad . \quad . \quad . \quad . \quad . \quad [17]$$

By means of this formula the values of the modulus of elasticity for

any type of strand may be determined. If $E_1 = E_2 = E_3$, the modulus of elasticity of any strand $E_s = E_1$.

45 Considering a rope, the formula for modulus of elasticity takes the same form, only for E_1 we substitute E_s, using the following notation:

ϕ = angle of strands in the rope
N = number of strands in rope
d = diameter of strands
$\frac{\pi d}{\sin \beta}$ = exact circumference pitch circle

where

β = angle subtended at center of rope by radius of strand
$\frac{d}{\cos \phi}$ = elongated diameter of strand normal to axis of rope in the twisted arrangement
$\frac{\pi d}{\sin \beta \cos \phi}$ = exact circumference pitch circle of strands of rope in the twisted arrangement
E_r = modulus of elasticity for rope

In a similar manner as before,

$$E_r = E_s \cos \phi \sqrt[2]{\frac{C \sin \beta \cos \phi}{\pi}} \quad . \quad . \quad . \quad . \quad . \quad . \quad [18]$$

46 For a compound rope of several layers of strands the modulus is determined as follows:

Let N_1, N_2, N_3, etc., represent the number of strands in successive layers, E_{r_1}, E_{r_2}, E_{r_3}, etc., the corresponding moduli and E_{mr} the mean modulus of rope. Then

$$E_{mr} = \frac{N_1 E_{r_1} + N_2 E_{r_2} + N_3 E_{r_3} + \text{etc.}}{N_1 + N_2 + N_3 + \text{etc.}} \quad . \quad . \quad . \quad . \quad [19]$$

For a compound rope such as one of 6 ropes each having six 7-wire strands:

Let Y = angle of rope strands in rope
ψ = angle subtended at center of rope by radius of rope strand
E_R = modulus of elasticity of compound rope

Then

$$E_R = E_r \cos Y \sqrt[2]{\frac{C \sin \psi \cos Y}{\pi}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [20]$$

Table 3 gives values of E_s and E_R as obtained from Formulas [17] and [18], and from the results of tests.

47 In obtaining the values of modulus of elasticity enumerated in Table 4, the value of E has been taken as 27,500,000 lb., since wire used in rope manufacture will not average much higher than 27,500,000. In fact, it may go as low as 25,500,000 and very rarely does it go as high as 29,000,000 lb. Soft bar steels on the contrary have a modulus of elasticity running about 29,000,000. Having determined the value of E_r for a given rope, the bending stress is readily obtained by use of the formula $S = E_r d/D$.

48 The tables of bending stress (Tables 7 to 11) as given are based upon a modulus of elasticity of 12,000,000. Some tests on

TABLE 3 MODULI OF ELASTICITY OF STRANDS AND ROPES

No. of Wires	Approx. Value of θ for Outer Layer of Wires	Cos θ	Value of Modulus E_s by Formula	Average of Tests
7	9°-54′	0.9851	19,950,000	20,000,000
19	15°-30′	0.9636	17,760,000	18,000,000
37	16°-33′	0.9586	16,900,000	16,700,000
61	17°- 8′	0.9556	16,600,000	17,000,000

Rope Construction	Approx. Value of θ for Strand Angles	Cos θ	Value of Modulus E_r by Formula	Average of Tests
6 × 7	14°-40′	0.9674	13,000,000	12,800,000
6 × 19	17°-52′	0.9518	11,400,000	11,400,000
8 × 19	20°-44′	0.9352	10,500,000	10,000,000
6 × 37	17°-52′	0.9518	10,800,000	10,400,000
6 × 42	19°-15′	0.9441	7,800,000	7,000,000

new ropes show a modulus less than this value, but after rope has been in service a short time the initial stretch having been partially taken out of it, the lay of the rope is altered somewhat and the modulus of elasticity is increased. This is more noticeable in ropes such as 8 x 19 construction where the stretch will be greater than in the case of 6 x 19, owing to the larger hemp center. The initial modulus of elasticity, therefore, of a 8 x 19 rope may run down to 6,000,000 lb., but it would not be safe to use this value in the calculation of bending stress when it is known that the modulus will increase more rapidly after a very short service. Modulus-of-elasticity curves of 6 x 7, 6 x 19, 8 x 19 and 6 x 37 rope specially designed to give a maximum flexibility are shown in Figs. 4 to 11.

REVERSE BENDING

49 The value of reverse bending may be determined in exactly the same way as that of direct bending, but its effect is very deleterious, even if the amount is comparably small. If it were possible in the design of a machine not to have any reverse bends, the rope service would be much better; or, if a reverse bend is necessary, let it affect only one part of the rope, in which case the effect might be the same as that of simple bending.

50 There is one misconception in regard to bending which should be discussed at this point and that is, that it makes no difference whether a bend is 90 deg. or 180 deg. provided it goes around a sheave of a fixed diameter. The stress produced is the same in each case

TABLE 4 PULL IN POUNDS FOR 1000-LB. LOAD
(16-in. sheaves, 2-in. pins)

No. of Parts of Rope	Sizes of Rope			
	5/8 in. 6 × 19	3/4 in. 6 × 19	7/8 in. 6 × 19	1 in. 6 × 19
2	529	534	540	547
3	359	364	369	375
4	274	279	284	289
5	223	228	233	239
6	189	194	199	205
7	165	170	175	180
8	147	152	157	162
9	133	138	143	148
10	122	126	131	137

and with the rope traveling between any two points all of the rope will have to take the bend whether it is 90 deg. or 180 deg. The only point to be noted is that the bend is effective for a small fraction of a second longer in case it is 180 deg. as compared with 90 deg. In bending rope around sheaves, as already explained, there is a loss of strength due to this bending. There is also a friction due to the ropes' passing around the sheaves and the journal friction of the sheave in its bearings which must not be lost sight of.

51 It is a comparatively easy matter to obtain the values of pull with any number of parts of rope lifting a given load and thus determine the loss of strength and friction factor which should be taken into account. Table 4 gives values of this pull under certain conditions, which are based upon the most favorable alignment of wire rope in the sheave blocks.

52 The conditions governing the use of multiple sheaves for hoists are so varied that it would be impossible to give data covering all conditions that would be met in actual service. The point that should be emphasized is that this factor should not be lost sight of in any calculation of importance, and its value, if unknown, should be allowed for by a somewhat larger factor of safety.

53 A word of caution also in regard to the use of a large number of parts of rope of small diameter should be noted. It is impossible for the stress in a large number of rope parts to distribute itself quickly in case the load comes upon the sheave-block assembly suddenly. For this reason the number of parts of the rope under such conditions should be kept at a minimum and the diameter of the rope increased so that the peak stress caused by the sudden application of load can distribute itself without serious results. Ropes have

FIG. 13 STRESS IN HORIZONTALLY SUSPENDED ROPE

been known to break under what was calculated to be a light load due to conditions similar to those just described.

STRESSES IN A HORIZONTALLY SUSPENDED CABLE SUPPORTING A LOAD

54 In this case a stress is produced in a rope suspended horizontally between two points due to the weight of the rope alone, and any load supported by the rope produces an additional stress which in most cases is not equal to the load but several times it in value. In the case of a horizontally suspended rope, Fig. 13, assuming the curve to be parabolic in form we may calculate stresses in a rope as follows:

Let L = total span in feet = AB
D = sag in feet = EF
W = live load at point F
w = weight per foot of the cable
S = tension in the cable at F

Then, for the stress due to weight of rope alone,

$$S_1 = \frac{wL^2}{8\,D} \text{ at the center of the span.} \quad . \quad . \quad . \quad . \quad [21]$$

55 Formula [21] is applicable to all cases of uniformly distributed load such as a wire rope or large guy strand used for supporting a lead telephone or power cable, or a bare-copper high-tension feeder cable, at frequent intervals. The value of w must be taken, however, as the total weight per foot of both suspended and supported cables.

56 The stress due to the weight alone is

$$S_2 = \frac{WL}{4D} \text{ at the center of the span.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [22]$$

$$S = S_1 + S_2 = \frac{wL^2 + 2WL}{8D} = \frac{L(wL + 2W)}{8D} \quad . \quad . \quad . \quad [23]$$

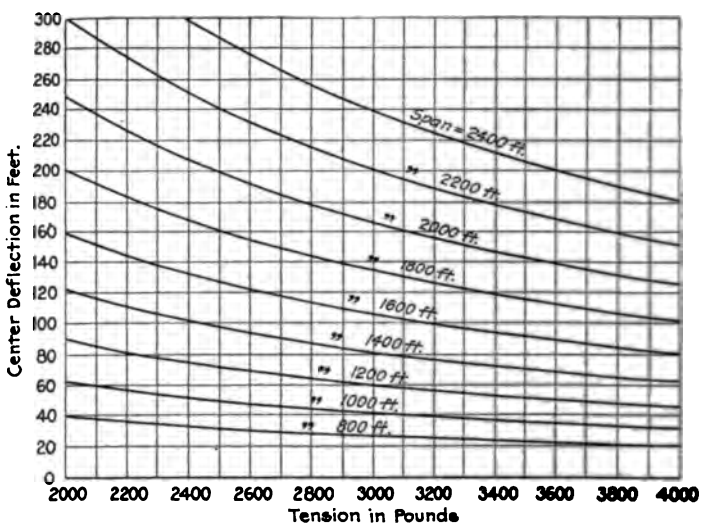

FIG. 14 TENSION IN CABLE SPANS IN POUNDS, FOR 1 LB. PER FT. DISTRIBUTED LOAD

From Formula [23] may be obtained the stress on any cable due to load and weight of cable.

57 The maximum stress on a cable span is at the supporting points A and B, Fig. 12, when the load is suspended in the center. Tension I at A or B equals tension in center plus the tension due to weight of rope wL and load W times the deflection D, or

$$T = \frac{S + D(wL + 2W)}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [24]$$

$$= S + D\left(w + \frac{2W}{L}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [25]$$

Figs. 14 and 15 give the tension in cable spans in lb. for a distributed load of 1 lb. per ft. Fig. 15 also gives the length of cable in a 1-ft. span for different ratios of span and sag.

PREPARATION OF SPECIFICATION FOR WIRE ROPE

58 In making up a specification for wire rope it is always advisable to consult with one or more rope manufacturers, giving them as much information as possible regarding the manner in which the rope is to be used, and ask for recommendations as to diameter, construction, and grade of rope which should be used. Most of the larger

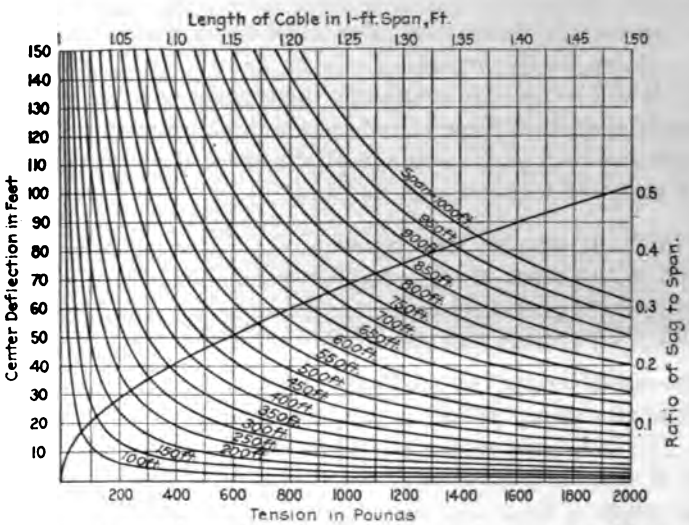

FIG. 15 TENSION IN CABLE SPANS IN POUNDS, FOR 1 LB. PER FT. DISTRIBUTED LOAD AND LENGTH OF CABLE IN 1-FT. SPAN FOR DIFFERENT RATIOS OF SAG AND SPAN

manufacturers have one or more experts who are studying rope applications from both theoretical and practical standpoints. Such information is given freely and a close coöperation between the manufacturer and the engineer will result in avoiding trouble which sometimes develops in a rope installation, or at least will improve rope service to the user. A few general remarks, therefore, in regard to specifications may not be out of place at this time.

59 Whenever possible specify and use some standard construction of wire rope such as 6 x 7, 6 x 19, 8 x 19, 6 x 37, or 6 x 61. The relative flexibilities of these constructions are in proportion to the diameters of the wires from which they are made. Taking the value

of the 6 x 7 rope as 100 the 6 x 19 will be 60; the 8 x 19, 50; the 6 x 37, 43; and the 6 x 61, 33. The sheave diameters will be in the proportion to the values for these rope constructions. Some rope installations may require special constructions but no manufacturer will specify a special construction if a standard one will do equally well.

60 Use the approximate strengths shown in the manufacturer's rope catalog of some one of the four standard strengths of steel known by the following trade names:

a Crucible steel
b Extra strong crucible steel
c Plow steel
d Special brand improved plow steel (each maker has a trade name for this brand).

61 It will be noted in comparing these tables of strength as given in rope catalogs that there are at least four solutions for a problem of simple hoisting, as an example of which for 6 x 19 rope to get a rope of about 82 tons strength we have:

	Strength, tons
$1\frac{3}{4}$-in. 6 x 19 crucible steel rope	85
$1\frac{5}{8}$-in. 6 x 19 extra strong crucible rope	83
$1\frac{1}{2}$-in. 6 x 19 plow-steel rope	82
$1\frac{3}{8}$-in. 6 x 19 monitor or special plow-steel rope	84

All rope manufacturers of the United States have standardized their rope strengths since 1910 by mutual agreement.

62 Table 5, showing the size of rope that may be bent around a sheave of any diameter of equal bending stress will be useful in comparing values of load that may be used on ropes of different constructions.

63 For certain purposes some engineers have attempted to specify the size of wire that should be used in a rope, but this is not desirable because there are certain refinements in rope manufacture, and unless they are put into effect by the manufacturers there will result an inferior rope. In specifying the strength of the finished rope, the metallic area has been fixed very closely and no reliable manufacturer would think of furnishing anything but the best possible rope.

64 Physical properties of wire are sometimes specified such as

a Tensile strength per square inch
b Elongation in 10 in.
c Bends over a fixed radius or proportionate radius
d Torsion test in 6- or 8-in. length.

65 *Tensile Strength.* Considering these in order, it is seen that taking a rope of a given diameter and metallic sectional area and allowing for the loss of efficiency due to angle of lay of wires, it will have to have at least a certain strength per square inch in order to meet the required breaking strength. For instance, a specification might be drawn up calling for a tensile strength of not over 200,000 lb. per sq. in., whereas it might require as much as 220,000 lb. per sq. in. to secure the required rope strength. A much saner specification would be to specify that the wire should not vary more than say

TABLE 5 CONSTRUCTIONS AND SIZES OF ROPES WITH EQUAL FLEXIBILITY

6 × 19 Rope Diameters, In.	Corresponding Diameters of 6 × 37 Rope, In.	Corresponding Diameters of 6 × 61 Rope, In.
9/16	3/4	1
9/16	3/4	1 1/8
5/8	7/8	1 1/4
13/16	1	1 3/8
3/4	1 1/8	1 1/2
7/8	1 1/4	1 5/8
1	1 3/8	1 3/4
1 1/16	1 1/2	1 7/8
1 1/8	1 5/8	2
1 3/16		2 1/8
1 1/4	1 3/4	2 1/4
1 3/8	2	2 3/8
1 1/2	2 1/8	2 1/2
1 5/8	2 1/4	2 3/4
1 3/4	2 3/8	3
1 7/8	2 1/2	3 1/4
2	2 3/4	3 1/2
2 1/8	3	3 3/4
2 1/4	3 1/4	4

10 per cent plus or minus from the average. This would insure material of reasonable uniformity from both user's and manufacturer's standpoint.

66 *Elongation.* The elongation of rope wire is not very great as compared to annealed wire and the diameter of the wire is the determining factor. A fixed value for elongation covering all sizes of rope wire is unfair as well as untrue to actual conditions of steel manufacture. If an elongation of 2.4 per cent in 10 in. were to be specified for a rope made of wire 0.150 in. in diameter, a smaller wire such as 0.075 in. or 0.038 in. would have a smaller elongation. The 0.038 size would probably not have an elongation over 1.2 per cent, for instance. Smaller wires would have even less elongation.

67 *Bends.* Bends are sometimes specified on rope wire, the object being to eliminate any brittle wire, but no manufacturer would knowingly permit a single piece of brittle wire to be used in rope construction, as all wire would be tested when finished to eliminate brittleness. Rope wire will stand approximately 6 bends of 90 deg. alternately to right and left over a jaw with a radius equal to twice the diameter of the wire being bent.

68 *Torsion Test.* A torsion test in 6 or 8 in. is used by most wire manufacturers to test the uniformity of rope wire. Some rope specifications call for a test for torsion on wires to be used in rope. While it should not be necessary to specify this, still ungalvanized rope wire should stand in 8 in. as many twists as are obtained by dividing the constant 1.8 by the diameter of wire in inches, and proportionate twists in shorter lengths.

When all has been said regarding physical tests, there is a tendency for rope makers to feel that their responsibility ceases whenever a customer specifies all the possible physical properties of both rope and wire, whereas if the manufacturer is given an opportunity to furnish a rope which he has recommended there will be a special effort made to furnish the best possible rope. In other words, a specification for a product as varied as wire rope should be more or less liberal and depend upon the performance of the rope in service for final judgment.

FACTORS AFFECTING ROPE SERVICE

69 One problem that is intimately linked up with rope service is the question of sheave diameter and the kind of bending to which a rope is subjected. Reverse bending should be avoided in every possible case as it has a very bad effect upon the durability of a wire rope.

70 For derricks the sheave diameter nowadays rarely exceeds 20 to 30 times the diameter of rope used, which is usually 6 x 19 or 8 x 19 construction. Hoisting machinery for coal towers, clamshell buckets for ore and coal handling are proportioned about forty times the rope diameter for 6 x 19 rope. Ladle cranes in steel mills use sheaves 30 times the rope diameter for 6 x 37 rope. Mine hoists use sheaves and drums from 60 to 100 diameters for 6 x 19 rope and these are probably the most liberally proportioned of any machinery. Lift bridges have sheaves and drums 50 to 80 times the rope diameter for 6 x 19 rope.

71 One point that seems to have been lost sight of in designing

TABLE 6 BENDING STRESS FOR 6 × 7 ROPE IN TONS OF 2000 LB.

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches									
	15′ 0″	14′ 0″	13′ 0″	12′ 0″	11′ 0″	10′ 0″	9′ 6″	9′ 0′	8′ 6″	8′ 0″
1½	5.04	5.40	5.82	6.30	6.87	7.56	7.96	8.40	8.89	9.45
1⅜	3.88	4.16	4.48	4.85	5.29	5.82	6.13	6.47	6.85	7.27
1¼	2.91	3.12	3.36	3.64	3.97	4.37	4.60	4.86	5.14	5.46
1⅛	2.09	2.24	2.42	2.62	2.86	3.14	3.31	3.49	3.69	3.92
1	1.49	1.60	1.72	1.87	2.04	2.24	2.36	2.49	2.64	2.80
⅞	1.03	1.11	1.19	1.29	1.41	1.55	1.63	1.72	1.82	1.94
¾	0.63	0.67	0.72	0.78	0.85	0.94	0.99	1.04	1.11	1.18
⅝	0.37	0.39	0.42	0.46	0.50	0.55	0.58	0.61	0.65	0.69
9/16	0.26	0.28	0.30	0.33	0.36	0.39	0.41	0.43	0.46	0.49
½	0.19	0.20	0.22	0.23	0.25	0.28	0.29	0.31	0.33	0.35
7/16	0.13	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.24
⅜	0.08	0.09	0.09	0.10	0.11	0.12	0.13	0.13	0.14	0.15
5/16	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.09
3/32	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.06

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches									
	7′ 6″	7′ 0″	6′ 6″	6′ 0″	5′ 6″	5′ 0″	4′ 6″	4′ 0″	3′ 6″	3′ 3″
1½	10.80	10.80	11.64	12.60	13.74	15.12	16.80	18.90	.....	.....
1⅜	7.76	8.32	8.96	9.70	10.58	11.64	13.94	14.54	.....	.....
1¼	5.82	6.24	6.72	7.28	7.94	8.74	9.72	10.92	.....	.....
1⅛	4.18	4.48	4.84	5.24	5.72	6.28	6.98	7.84	8.96	.....
1	2.98	3.20	3.44	3.74	4.08	4.48	4.98	5.60	6.40	6.88
⅞	2.06	2.22	2.38	2.58	2.82	31.10	3.44	3.88	4.49	4.76
¾	1.26	1.34	1.44	1.56	1.70	1.88	2.08	2.36	2.68	2.88
⅝	0.74	0.78	0.84	0.92	1.00	1.10	1.22	1.38	1.56	1.68
9/16	0.52	0.56	0.66	0.66	0.72	0.78	0.86	0.98	1.12	1.20
½	0.38	0.40	0.43	0.46	0.50	0.56	0.62	0.70	0.80	0.86
7/16	0.26	0.28	0.30	0.32	0.36	0.38	0.43	0.48	0.56	0.60
⅜	0.16	0.17	0.18	0.20	0.22	0.24	0.26	0.30	0.34	0.36
5/16	0.09	0.10	0.10	0.12	0.12	0.14	0.16	0.18	0.20	0.21
3/32	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.14	0.15

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches									
	3′ 0″	2′ 9″	2′ 6″	2′ 3″	2′ 0″	1′ 9″	1′ 6″			0′ 9″
1	7.48	.....	.....	.....	.....	.....	.....	.....	.....	.....
⅞	5.16	5.64	6.20	.....	.....	.....	.....	.....	.....	.....
¾	3.12	3.40	3.76	4.16	4.72	.....	.....	.....	.....	.....
⅝	1.24	2.00	2.20	2.44	2.76	3.12	.....	.....	.....	.....
9/16	1.32	1.44	1.56	1.72	1.96	2.24	2.64	.....	.....	.....
½	0.92	1.00	1.12	1.24	1.40	1.60	1.84	.....	.....	.....
7/16	0.64	0.70	0.76	0.86	0.96	1.12	1.28	.....	.....	.....
⅜	0.40	0.43	0.47	0.52	0.59	0.68	0.79	.....	.....	.....
5/16	0.23	0.24	0.28	0.31	0.35	0.39	0.47	.....	.....	.....
3/32	0.16	0.18	0.20	0.22	0.24	0.28	0.33	.....	.....	.....

72 The final criterion as to whether the stresses in a wire rope for any given class of service have been properly calculated and the

TABLE 8 BENDING STRESS FOR 6 × 37 ROPE IN TONS OF 2000 LB.

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches									
	14′ 0″	13′ 0″	12′ 0″	11′ 0″	10′ 0″	9′ 0″	8′ 0″	7′ 6″	7′ 0″	6′ 6″
2¾	11.11	11.97	12.96	14.15	15.56	17.40	19.45	20.75	22.22	23.91
2½	8.35	8.99	9.74	10.63	11.69	12.99	14.61	15.60	16.70	17.96
2¼	6.09	6.55	7.10	7.75	8.52	9.47	10.65	11.36	12.18	13.10
2	4.29	4.62	5.00	5.45	6.00	6.67	7.50	8.00	8.56	9.21
1¾	2.89	3.11	3.38	3.68	4.05	4.50	5.06	5.40	5.78	6.22
1⅝	2.29	2.47	2.68	2.92	3.21	3.57	4.01	4.28	4.58	4.93
1½	1.80	1.98	2.10	2.29	2.52	2.80	3.15	3.36	3.60	3.87
1⅜	1.39	1.49	1.62	1.77	1.94	2.18	2.43	2.59	2.78	2.98
1¼	1.04	1.12	1.22	1.33	1.46	1.62	1.82	1.95	2.08	2.24
1⅛	0.76	0.82	0.88	0.97	1.06	1.18	1.33	1.42	1.52	1.64
1	0.54	0.58	0.63	0.68	0.75	0.83	0.94	1.00	1.04	1.16
⅞	0.38	0.39	0.42	0.46	0.51	0.56	0.63	0.66	0.72	0.78
¾	0.23	0.25	0.26	0.29	0.31	0.35	0.39	0.42	0.46	0.50
⅝	.....	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26	0.28
9/16	.....	.....	.....	0.12	0.13	0.15	0.17	0.18	0.19	0.20

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches									
	6′ 0″	5′ 6″	5′ 0″	4′ 6″	4′ 0″	3′ 9″	3′ 6″	3′ 3″	3′ 0″	2′ 9″
2¾	25.92	28.30	31.12	34.80	38.90	41.50	.....	.....	.....	.....
2½	19.48	21.26	23.38	25.98	29.22	31.20	33.40	35.96	.....	.....
2¼	14.20	15.50	17.04	18.94	21.30	22.72	24.36	26.20	.....	.....
2	10.00	10.90	12.00	13.34	15.00	16.00	17.16	18.46	20.00	21.[illegible]
1¾	6.76	7.36	8.10	9.00	10.12	10.80	11.56	12.44	13.52	14.[illegible]
1⅝	5.36	5.84	6.42	7.14	8.02	8.56	9.16	9.86	10.72	11.[illegible]
1½	4.20	4.58	5.04	5.60	6.30	6.72	7.20	7.92	8.40	[illegible]
1⅜	3.24	3.54	3.89	4.36	4.86	5.18	5.56	5.96	6.48	[illegible]
1¼	2.44	2.66	2.92	3.24	3.66	3.90	4.16	4.48	4.88	[illegible]
1⅛	1.76	1.94	2.13	2.36	2.66	2.84	3.04	3.28	3.54	[illegible]
1	1.26	1.36	1.50	1.66	1.88	2.00	2.08	2.32	2.52	[illegible]
⅞	0.84	0.92	1.01	1.12	1.26	1.36	1.44	1.56	1.68	[illegible]
¾	0.52	0.58	0.63	0.70	0.78	0.84	0.92	1.00	1.04	[illegible]
⅝	0.30	0.33	0.36	0.40	0.44	0.48	0.52	0.56	0.61	[illegible]
9/16	0.22	0.24	0.27	0.30	0.33	0.36	0.38	0.41	0.44	[illegible]
½	.....	.....	.....	.....	0.23	0.25	0.26	0.29	0.31	[illegible]
7/16	.....	.....	.....	.....	.....	.....	.....	.....	0.21	[illegible]
⅜	.....	.....	.....	.....	.....	.....	.....	.....	0.13	[illegible]

design of the machinery suitably laid out will be evidenced by whether the rope is giving good service or not. In the foregoing discussion no mention has been made of a factor which is of great importance,

namely, what might be called the service factor, a short explanation of which will show what is meant.

73 The first element which should be considered under this heading is the personal equation of the operator who is to handle the wire rope. The skill with which any rope is handled coupled with freedom from sudden jerks or quick stops vitally affects the entire problem. The element aside from the personal equation which must be considered is the external wear or abrasion of the wires composing the rope. Properly aligned sheaves, leads that are not excessive, and absence of any points where friction would cause undue wear, will all contribute to longevity of rope service. If the external wear is

TABLE 9 BENDING STRESS FOR 6 × 37 ROPE IN TONS OF 2000 LB.

Diam. of Rope in Inches	Diameter of Sheave or Drum in Feet and Inches						
	2′ 6″	2′ 3″	2′ 0″	1′ 9″	1′ 6″	1′ 3″	1′ 0″
2	24.00	.....	.....	.....	.....	.....	.....
1¾	16.20	18.00	20.24	.....	.....	.....	.....
1⅝	12.84	14.28	16.04	18.32	.....	.....	.....
1½	10.08	11.20	12.60	14.40	.....	.....	.....
1⅜	7.78	8.72	9.72	11.12	12.96	.....	.....
1¼	5.84	6.48	7.32	8.32	9.76	11.68	.....
1⅛	4.26	4.72	5.32	6.06	7.08	8.52	.....
1	3.00	3.32	3.76	4.16	5.04	6.00	7.52
⅞	2.02	2.24	2.52	3.08	3.36	4.04	5.04
¾	1.26	1.40	1.56	1.84	2.08	2.52	3.12
⅝	0.73	0.80	0.92	1.04	1.22	1.40	1.84
9/16	0.54	0.60	0.66	0.76	0.88	1.08	1.32
½	0.38	0.41	0.46	0.52	0.62	0.76	0.92
7/16	0.25	0.28	0.31	0.39	0.42	0.50	0.62
⅜	0.16	0.17	0.19	0.23	0.26	0.32	0.38

excessive, the rope maker can only partially overcome this difficulty by the use of stronger and harder grades of steel. Mention has already been made of the four commercial brands of steel, namely, crucible steel, extra strong crucible steel, plow steel, special high-strain or improved plow steel. Of these four grades crucible is the softest and improved plow steel the hardest.

74 It might be thought at the first glance that all it is necessary to do to solve the problem of abrasion is to use the hardest possible steel. This is not necessarily true, because each of the four grades referred to above has physical characteristics that are possessed by the others, only in a greater or lesser degree. If, therefore, in the design of a machine requiring wire rope it is found that crucible steel

rope of standard 6 x 19 construction is about 12,000,000; or, in other words, that the rope stretches about 2.3 times as much as would one made of straight wires. Different investigators in the past have found values of this function ranging from 12,000,000 to 17,000,000. For any given rope its value depends somewhat upon the age and condition of the rope. For a new, well-lubricated rope, 12,000,000 is correct; while in an older rope, in which the hemp center has been compressed and has become hardened, a larger value will be found. If, however, the rope is subjected to bending over small sheaves, the hemp center will be continually worked and stretched, and the rise in the value of the modulus of elasticity will be much smaller.

It is not difficult to explain why the rope stretches more than would a bundle of straight wires. A 6 x 19 rope is composed essentially of 114 spiral springs. Under tension these springs stretch out, the diameters of the helices reducing slightly. This stretching-out action does not occur freely, as the tightly twisted wires and strands interfere with each other. In a new, well-lubricated rope the helical strands can pinch down considerably on the elastic core, the amount of stretching out is large, and the modulus is small; while after the core compresses and becomes hardened the strands cannot pinch down so much, the amount of stretching out reduces, and the modulus becomes greater.

Mr. Howe discusses the question of the stiffness of an ordinary wire rope as compared with that of a rope composed of straight wires, calling attention to the fact that the ordinary rope is much more flexible. He concludes that, on account of the lower modulus of elasticity in tension of the ordinary rope, the bending stresses produced in the individual wires are correspondingly smaller than those in the straight wires, and thus accounts for the greater flexibility. From this reasoning we would expect the ratio of the stiffnesses of the two ropes to be 2.3 to 1. Actually, however, this ratio is much larger than 2.3 to 1. The writer suggests the following explanation of the greater flexibility of the ordinary rope:

If a rope composed of straight wires, having the same number and arrangement of wires and strands as the standard 6 x 19 rope, be bent around a sheave, certain wires will lie on the outside of the curve throughout, and must evidently elongate and be subjected to tensile stresses in addition to bending stresses, while other wires will lie on the inside of the curve throughout, and will receive compressive stresses as well as bending stresses. On account of the

ıxial stresses being thus produced in the wires, the stiffness of the ·ope will be much greater than that of the 114 wires themselves – about 200 times as great if all of the stretching or shortening of he wires has to occur in the bent portion of the rope, and probably ;0 to 100 times as great if the stretching or shortening of the wires 'an extend out into the straight portions of the rope, as will usually ›e the case.

Consider now a piece of ordinary 6 x 19 wire rope, say 1 in. in liameter. The strand which lies at the top of the rope at one ›oint is at the bottom about 3 in. away; and the wire lying at the op of a strand at one point is at the bottom about $1\frac{1}{4}$ in. away. If ıuch a rope, well lubricated, be bent around a sheave, evidently it s unnecessary that any large axial stresses be set up in the wires. 'nstead, the strands will slip along the core and the wires will slip ılong each other in the strands. Evidently, then, the wires will ›e subjected to bending stresses, and in addition only to sufficient ıxial stresses to make the strands slip along the core and the wires ılong each other. These axial stresses will be negligible in a well-ubricated rope.

From the foregoing it is clear that the ordinary rope is much nore flexible than the rope composed of straight wires, for the eason that in bending the latter there are set up large axial stresses, s well as bending stresses, in the individual wires, while in bending he former there are set up bending stresses only in the wires. Evi-ently, therefore, we cannot argue from the greater flexibility of the rdinary rope that the bending stresses in the wires are smaller han those in the rope composed of straight wires.

Mr. Howe, having deduced 12,000,000 as the value of the modu-ıs of elasticity in tension for the entire rope, then assumes that this alue can be used in computing the bending stresses in the sep-rate wires, and thus obtains values about half those which have enerally been accepted. The writer can see no direct reason why ıe modulus of elasticity in tension should necessarily apply to the ılculation of bending stresses in the separate wires, and feels that ıe author should give his reasons for making this assumption. 'he point certainly requires explanation.

The writer has put considerable study on the question of bend-ıg stresses in wire ropes, and offers the following formula. It is mple and logical in derivation, so far as he can see, and it agrees ·ith the only tests bearing directly on the question of which he has ny knowledge.

Suppose a straight wire of diameter d to be bent 180 deg. around a sheave of diameter D. The length of the bent portion of the wire is $\pi D/2$ and the total angle through which it is bent is π; so that the angle of bending per unit length is $\pi/(\pi D/2)$ or $2/D$. Letting f be the extreme fiber stress in the wire and E the modulus of elasticity of the material, the angle of bending per unit length is also $(f/E)/(d/2)$, or $2f/Ed$. We then have

$$\frac{2f}{Ed} = \frac{2}{D}$$

whence

$$f = E\frac{d}{D}$$

This latter expression is the formula given by Reuleaux, Rankine, Unwin, and other writers, and is evidently applicable to straight wires only.

Now consider a helical wire, such as the center wire of one of the strands of a wire rope. Let the angle between the wire and the axis of the helix be a, and other notation as before. Now suppose the helical wire bent 180 deg. around the sheave. The total angle through which the wire is bent is evidently π, as before, and the length of the bent portion is $(\pi D/2)$ sec a; so that the average angle of bending per unit length is evidently $\pi/(\pi D/2)$ sec a, or $(2/D)$ cos a. We then have

$$\frac{2f}{Ed} = \frac{2}{D}\cos a, \text{ whence} \qquad f = E\frac{d}{D}\cos a$$

Next consider a compound helical wire, such as one of the outer wires in a strand of a rope. Let the angle of lay of the strand be a, and the angle of lay of the wire in the strand be b. As before, suppose the wire bent 180 deg. around the sheave. The length of the bent portion of the wire is $(\pi D/2)$ cos a cos b, whence we find

$$f = E\frac{d}{D}\cos a \cos b$$

It appears difficult to the writer to consider the bending stresses to be any smaller than those given by the foregoing formulæ. The total length of the wire and the total angle through which it is bent are known, definite quantities in each case, from which we can deduce directly the average angle of bending per unit length; and from this latter quantity the extreme fiber stress in the wire can be computed directly and without any doubt whatsoever.

While the last-mentioned formula thus appears to be correct, it is, of course, very desirable to check it experimentally. The results of some experiments given in a paper by Mr. R. W. Chapman in the *Engineering Review* of October, 1908, entitled The Stress in Wire Ropes Due to Bending, offer an opportunity for such a check. Mr. Chapman took a short length of wire rope, clamped one end securely, applied transverse forces to the other end, and then measured the resulting deflections. Figs. 16 and 17 record graphically the results of two of his experiments.

In making such an experiment, evidently we must allow for the effect of the internal frictional forces between the various strands and wires. Mr. Chapman eliminated the effect of these forces in the following manner: He first applied a gradually increasing force in one direction, then reduced it gradually to zero, then applied a gradually increasing force in the other direction, and then gradually reduced it to zero. When the first small forces were applied the deflections were very small, as the wires and strands had not yet begun to slip on each other, and the rope had nearly the stiffness of a solid bar. The flat portion of the deflection curve just to the right of the origin in each figure corresponds to this stage. As the forces were increased the internal friction was overcome, the wires and strands began to slip freely on each other, and the deflection curve turned up sharply and continued practically a straight line as long as the forces were increased. The reduction of the forces then began. The resulting deflection curve was at first very flat, the rope acting as a solid bar while the direction of the internal frictional forces was reversing; then the curve turned down sharply as slippage in the opposite direction began. The forces were then gradually reduced to zero and then applied in the opposite direction, the deflection curve continuing downward as a straight line meanwhile. The forces were then reduced gradually to zero, the deflection curve being at first very flat, then turning up sharply and continuing as practically a straight line. The forces were again reversed in direction, the curve continuing upward and joining the curve first drawn, thus forming a complete loop.

In the loop just described the nearly horizontal portions at the top and bottom, as stated before, represent the deflection curve when no slippage of wires and strands occurs; while the long, steeply inclined sides represent the curve when the wires and strands are slipping freely, with the effect of internal friction eliminated.

Our next step is to compute the theoretical deflection curves for

each of the two examples in accordance with the formulæ for bending stresses deduced by Mr. Howe and the writer, and to plot them on the two figures.

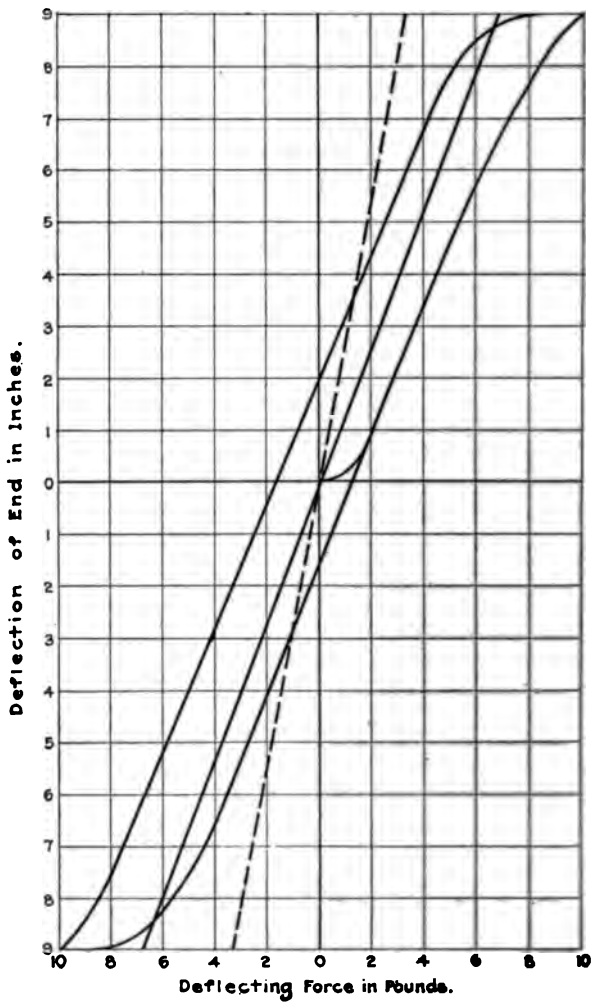

FIG. 16 DEFLECTION OF 6 x 12 WIRE ROPE WITH LOAD 24 IN. FROM SUPPORT

The rope used in the tests plotted in Figs. 16 and 17 consisted of 6 strands of 12 wires each, with a hemp core for the rope and hemp cores for the strands. The rope was of ordinary lay, the angle of lay being 18½ deg., and the diameter of the wires 0.082 in. The

moment of the inertia of the 72 wires is $72 \times 0.082^4 \times 0.0491 = 0.000159$. The value of EI, according to Mr. Howe's formula, is $12{,}000{,}000 \times 0.000159 = 1910$; while according to the writer's formula, since $\cos 18\frac{1}{2}$ deg. $= 0.95$, it is $27{,}500{,}000 \times 0.000159 \times 0.95 \times 0.96 = 3950$.

For Fig. 16, the distance from the support to the end of the rope was 26 in., and the distance from the support to the load was 24 in. The deflection y of the end for a load P is therefore

$$y = \frac{24\,P \times 12 \times 18}{EI} = \frac{5180\,P}{EI}$$

For Mr. Howe's formula, $y = 5180\,P/1910 = 2.71\,P$, and for the writer's formula, $y = 5180\,P/3950 = 1.31\,P$.

For Fig. 17, the distances from the support to the end of the

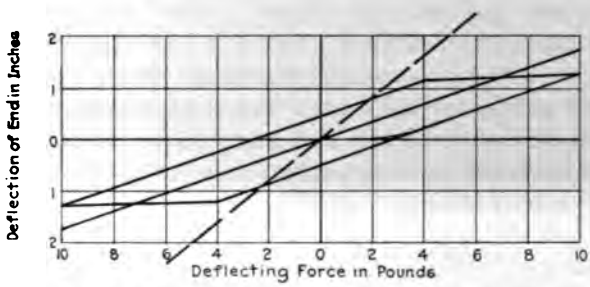

FIG. 17 DEFLECTION OF 6 X 12 WIRE ROPE WITH LOAD 12 IN. FROM SUPPORT

rope and to the load point are 14 in. and 12 in., respectively, so that the deflection of the end is

$$y = \frac{12\,P \times 6 \times 10}{EI} = \frac{720\,P}{EI}$$

For Mr. Howe's formula, $y = 720\,P/1910 = 0.376\,P$, and for the writer's formula, $y = 720\,P/3950 = 0.182\,P$.

The deflection curves computed by the writer's formula have been plotted on each of the two figures as straight full lines, and those figured by Mr. Howe's formula as straight dotted lines. It will be noted that in each figure the full line is approximately parallel to the deflection curve when the wires and strands are slipping freely, with the effect of internal friction eliminated; while the dotted line does not agree at all with these deflection curves. These tests therefore indicate the substantial correctness of the formula

termine from information obtained that the rope subjected to it has in all instances required more frequent renewal than the other ropes. There is another question in the use of rope that has not been touched upon by the author and that frequently comes up in meeting the conditions in mine hoisting from great depths. This is, To what extent does the winding of the rope in more than one layer on the drum affect the longevity of the rope? What effect does the second layer of the rope have on the first, and the third layer on the second?

With reference to lubrication of rope, there are occasions when I believe this is not desirable, and that is in cases of haulage ropes, where the rope is liable to be dragged on the ground. The lubricant here tends to pick up the sand and grit, which necessarily is forced into the rope when the rope is wound on the drum and would tend to increase the wear on the rope.

C. C. Brooks (written). Mr. Howe's allusion to the effect on the stresses in the rope due to bending over sheaves, is, I believe, timely, for it is frequently found that where the arc of contact of the rope around the sheave is slight the ropes are led over sheaves much smaller in diameter than the best accepted practice demands, there being a prevalent feeling that the life of the rope is not seriously affected by slight change in direction, as it would be by one considerably greater. Consequently, small deflecting rollers are employed, causing early fracture of the outside wires.

The emphasis Mr. Howe has laid upon the part the personal equation of the operator plays in determining the life of the rope cannot be made too great, for my own observation leads me to feel that more depends upon this one factor than on any other, especially where the ropes are employed in the handling of materials, that is, for intermittent service. Operators are all too prone to start and stop as suddenly as the mechanism operating the various sheaves or drums will permit, thereby inducing whipping of the lines and also inducing waves, as it were, to travel along them, causing serious abrasions of the outer wires of the strands through the rubbing action against the sheave grooves and its guards.

Albert Reichmann[1] (written). I should prefer to have Par. 22 stated as follows:

> 22 In the case of a moving rope, supporting a load, the stress in the rope is equal to the load itself, when the speed is

[1] American Bridge Co., 208 S. La Salle St., Chicago, Ill.

uniform, whether it is great or small. As soon as there is a change of velocity there is a change of stress in the rope. For a uniform change of velocity the change of stress in the rope will be that called "stress due to acceleration or retardation." For a change of velocity which is not uniform, but abrupt or sudden, stresses are induced which should be classified as impact stresses.

The first kind can be obtained in the following manner:

Generally speaking, the relation between a constant force F acting on a moving body, the mass of the body m and its acceleration a, is $F = \pm ma$. If the force is gravity, the mass is expressed by W/g, where W is the weight of the moving body and g the acceleration of gravity. Hence $F = \pm Wa/g$.

This simple relation is all that is necessary to establish the stress actors given in Table 1 for various assumed accelerations a. Thus or $a = 8.02$ the stress factor $= 8.02/32.2 = 0.249$, and hence the otal stress in the rope is $1.249\ W$.

Par. 54 should point out how the stress in a suspended cable ttached at any two points could be found and not only for a cable etween two points on the same horizontal line.

Par. 57 gives an expression for the tension at the points of attachnent of a cable which does not seem to agree with ordinary ideas f statics. This tension ought to be expressed by

$$T = \sqrt{S^2 + \tfrac{1}{4}(wL + W)^2}.$$

Lyman H. Miller (written). The important subject of reversng stresses is one constantly before the wire-rope manufacturer, lirecting and guiding his practice. Perhaps the best confirmation f this is the fact that in the so-called "life test" the rope is not nly subjected to a severe bending stress but receives a reverse end.

F. Hymans (written). The first problem considered by Mr. Iowe consists of the determination of the strength of a strand omposed of 7 wires of equal diameter, for which he derives the ormula:

$$W_s = S + 6\,S\cos\theta$$

n which W_s is the breaking strength of the strand and S that of a vire. This equation is built upon the supposition that if the strand s loaded with a force W_s, the forces along the axis of the center wire

and along the axis of the outer wires will each have the same magnitude S. As the following will show, this is not true.

Referring to Fig. 18, AB represents the free length of the strand, which is at the same time the free length of the center wire. The outer wires each form a helix wound on the center wire, and if CB is the circumference of the base circle of the helix, AC will be the free length of an outer wire. If now a force S acts at B as well as at C along the axes of AB and AC, the elongations BB_1 and CC_1 — since the size of the wires is the same — will be proportional to the free lengths AB and AC. And if Mr. Howe's version of the matter is correct, AB_1 and AC_1 will be the altered lengths of the center and outer wires when the strand is loaded.

In reality, however, things are different. The outer wires before and after loading form a helix of which the base circle remains

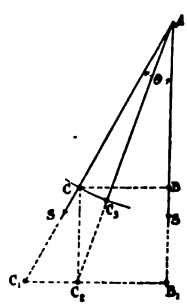

FIG. 18 DIAGRAM SHOWING ALTERED LENGTHS OF CENTER AND OUTER WIRES WHEN STRAND IS LOADED

substantially the same, since the load causes only infinitesimal changes in the diameter of the strand. If, therefore, in Fig. 18 AB_1 is the altered length of the middle wire, we merely have to lay off $B_1C_2 = BC$ to find AC_2, the altered position and length of the outer wire AC. If we further make $AC_3 = AC$ we find the elongation of the outer wire to be C_2C_3 and not CC_1 as Mr. Howe would have it. It will be seen that C_2C_3 is smaller than CC_1, from which follows that the force along the axis of the outer wire is not S but is smaller. Therefore, if a strand composed of equal wires is loaded axially, the force along the axis of the center wire will be greater than the force along the axis of the outer wires, and not the same as assumed in Mr. Howe's formula. The same error is contained in Formulæ [3], [4], and [7] of the paper.

In the consideration of the effect of acceleration, Par. 22, Mr. Howe runs afoul of fundamental dynamics. In his Formula [9], $K_t = C\,(W + wl)$, K_t denotes the total kinetic energy of the moving system, W the weight of the load, wl the weight of the rope, and C is defined as the factor by which the load is increased due to kinetic energy. This definition, however, defective as it is, is wholly at variance with his formula; for according thereto C is the factor by which the weight of load plus rope must be multiplied to obtain the kinetic energy and has nothing to do with an increase in the load. Owing to this confusion the result of the calculations presented in Table 1 is utterly wrong.

The problem, as presented by Mr. Howe, is perfectly simple, yields directly to the application of the most fundamental law of dynamics, and does not require the devious route of operation with kinetic energy and the subsequent employment of formulæ which

FIG 19 DIAGRAM TO ILLUSTRATE FORCE REQUIRED TO ACCELERATE A LOADED ROPE

apply only to uniformly accelerated motion. Evidently it is this: Referring to Fig. 19, what is the force X applied to the end of a rope weighing wl and from which is suspended a weight W, when the system is to receive the acceleration a? By Newton's law the resultant of all forces equal mass times acceleration, whence

$$X - W - wl = \left(\frac{W + wl}{g}\right) a$$

or

$$X = (W + wl)\left(1 + \frac{a}{g}\right)$$

To find the force X we must therefore multiply the suspended weights by the factor $\left(1 + \frac{a}{g}\right)$.

For example, if the acceleration is 17.93 ft. per sec², this factor is $1 + \frac{17.93}{32.16} = 1.557$, whereas the value given in Table 1 is 6. If

the factor of safety of the rope for static load was 10, an acceleration of 17.93 would reduce it to 10/1.577 = 6.42 and not to 1.67 as in the table.

It should be remarked that in Mr. Howe's consideration, as well as in the corrected formula above, the rope is assumed to be perfectly rigid. If its elasticity is taken into account, however, the problem becomes much more complicated, as is shown in the writer's paper on Stresses in Machines when Starting or Stopping, page 155 *ante*.

In Pars. 39 to 46 Mr. Howe undertakes the determination of the modulus of elasticity of a strand and of a rope. Now a formula, empirical ones excepted, to be logical must be the translation into mathematical language of a conception or definition. What, then, is the conception or definition of the modulus of elasticity of a rope? Mr. Howe gives none; but the one heretofore met in literature on ropes is an artificial concept, somewhat akin to Young's modulus. The latter, as is known, is the quotient obtained by dividing the tensile stress per square inch by the elongation, reckoned per unit of length. If, therefore, a straight prismatic bar, initially of length L and cross-section A, is uniformly loaded normally to each cross-section by a force P, which produces the elongation ΔL, Young's modulus will be expressed by

$$E = \frac{P}{A} \times \frac{1}{\frac{\Delta L}{L}}$$

Similarly for a strand or a rope; with this difference, however, that P is the force applied to the ends of the strand or rope, without specification as to its distribution, and that A is not the cross-section of the rope normal to its axis, but is the aggregate area of the cross-sections of the individual wires. However that may be, it is quite clear that in an analytical determination of the modulus of elasticity of a rope, the first object is the derivation of the elongation produced in it by a given force. If there is in Pars. 39 to 46 any attempt in that direction, the writer would be glad to have it pointed out to him, as well as what fundamental conception, for instance, underlies Formulæ [17] and [19].

Passing now to the discussion of Mr. Howe's formula for the stresses in a bent rope: If a straight cylindrical bar of diameter d and made of homogeneous isotropic material, for which Young's modulus is E, is given a curvature of diameter D, we know from the

theory of elasticity (and not from Reuleaux) that the outer fiber stress is expressed by $S = Ed/D$. Mr. Howe merely replaces E by E_r, the modulus of elasticity of the rope, and proclaims, without further proof, the so-modified formula to be the true one with which to figure the stress in the wires of a bent rope. It would indeed be gratifying if we could determine the elasticity of ropes by the simple expedient of replacing E by E_r in the known formulæ of the theory of elasticity, but can we?

For example, if the elongation per unit length of a bar is ΔL, we know that the tensile stress in each fiber is expressed by $S = \Delta L \times E$. Now, by writing $S = \Delta L \times E_r$, do we get the tensile stress in the wires of a rope when it has received an elongation amounting to ΔL per inch of length?

Or again, the relation between the modulus of shear G and Young's modulus is expressed by $G = \frac{m}{2(m+1)}E$, m being Poisson's ratio. Do we obtain the modulus of shear of a rope (whatever that may be) if we replace E by E_r?

In neither of these examples do we obtain the desired result, which shows at least that the process of replacing E_r by E is not generally permissible. However, it is also not permissible in the so-called Reuleaux formula, as the following will show.

In the determination of stresses we need quantities as Young's modulus or the modulus of shear, which link *elementary deformations* at a point of a body with the *stresses* associated with them. The modulus of elasticity of a rope, however, links together the *elongation of the entire rope* and the *force* producing the elongation, *reckoned per square inch of the aggregate cross-sections of the wires.* Now the elongation of the rope is not the same as that of the wires composing it; for a strand, for example, the elongation is the same as that of the center wire, but is different for each successive layer of outer wires. The elongation of a *rope* is therefore no direct measure for the state of deformation of a *wire*. Again, the force per square inch of the aggregate cross-sections of the wires bears no direct relation to the stress which it causes in the individual wires. The modulus of elasticity of a rope is therefore a purely artificial concept, not connecting the stress in a given point of the wire with the deformation produced by it. If we say that Young's modulus is 30,000,000, we express the fact that at any point of the body and in any direction, a pull of 1 lb. per sq. in. produces an elongation of 1/30,000,000 in. However, if we say that the modulus of elas-

ticity of a rope is 12,000,000, we mean no more than that an axial force of 1 lb. for each square inch of cross-section of the wires produces an elongation of the *rope* of 1/12,000,000 in. per unit of length, but have no inkling whatsoever of the deformation or stress in a given point of a *wire*. It is therefore clear that where E and E_r stand for things so totally different, no formula of the theory of elasticity can be made to apply to ropes by merely writing E_r for E.

THE AUTHOR. The formula as proposed by Mr. Hardesty, namely,

$$f = E\frac{d}{D}\cos a \cos b$$

will give as applied to ordinary 6 x 19 wire rope, assuming that $\cos a = 0.95$ and $\cos b = 0.95$, a value for $\cos a \cos b$ of 0.9025. If this is multiplied by E, it will mean, assuming E to be 27,500,000 as proposed by the writer in his paper, that the modulus of elasticity of the entire rope would be equal to the product of 0.9025 and 27,500,000 or 24,818,750 lb.; or in other words, the modulus of elasticity of the wire rope would be only about 10 per cent less than the modulus of the straight wires. Experimental proof has shown that the modulus is much less than this, as will be noted by reference to the curves shown in Figs. 6 and 7.

Reference has been made by Mr. Hardesty to the paper by W. R. Chapman, published in the *Engineering Review* in 1908, in which Mr. Chapman gave particulars of experiments made to show the value of the bending stress in wire ropes. In that paper Mr. Chapman gives for a 3¼-in.-circumference rope (1.034 in. diameter) a bending stress of 18,945 lb. over a 3-ft. sheave. This corresponds to a modulus of elasticity of approximately 24,300,000 lb., which agrees with Mr. Hardesty's formula. However, Mr. Hardesty is basing his conclusions entirely upon the Chapman experiments, so that the agreement of his formula with the Chapman experiments is by no means conclusive evidence of the correctness of the assumptions which have been made.

The entire experimental proof of Mr. Chapman rests upon a series of experiments made by clamping a piece of wire rope in a solid jaw, suspending this rope vertically and then applying various loads at the end of this rope and recording the deflections. For ordinary testing where the material being tested is a solid, this method would probably give fairly correct results; but in testing

wire rope in this manner, very serious complication has been allowed to creep in which completely nullifies the results obtained. This will be readily understood when the structure of wire rope is examined. When the clamp is placed upon the wire rope, it is bound solid and no action can take place. Furthermore, the lower end of the wire rope must be held solid in a seizing of wire. This prevents any play of the strands either at the end of the rope or at the point where they are clamped. The distance in between is so short that it seriously affects the results obtained, because it gives a much greater stiffness to the rope than is possessed by the rope under actual working conditions. Any person who has handled wire rope knows that the effect of binding both ends of a short piece of rope is to render it very stiff. If the piece of rope is lengthened, this stiffness is overcome. However, experiments of this kind, while they are interesting, do not give true results as to the working of a full-length specimen of rope, and this is what the engineer wants to know. Behavior of a short specimen under bending does not concern him. It is what the specimen will do when it is put to work in commercial lengths on a large outfit.

Taking the case already cited, namely, the 1.03-in.-diameter rope working over a 3-ft. sheave, the bending stress on a sheave 1 ft. 6 in. in diameter would be, according to Mr. Chapman, 18.94 tons. A rope of this diameter would have an ultimate strength of 30 tons for crucible steel, or 38 tons for plow steel. It is not an unusual case for a derrick to be equipped with rope working under these conditions and carrying a load of 6 to 7 tons. Were the bending stresses as high as these Chapman experiments would indicate, the life of the rope would be exceedingly short, because the material would be worked at or near the elastic limit at all times, even without any additional load. Other similar cases might be cited wherein these conditions are duplicated. This of itself is conclusive proof that the bending stress cannot be as great as would be computed either by the Chapman formula or by Mr. Hardesty's formula as he proposes it.

Were the stress as high as calculated by Messrs. Chapman and Hardesty, wire rope would give practically no service at all under the conditions noted, whereas we know of numerous cases where ropes have lasted from six to eighteen months under conditions similar to those just noted. The practical results of rope operation offer added proof, therefore, that the bending stress is a much smaller factor than indicated by Mr. Hardesty's calculations.

Referring to the discussions of Messrs. Moeller and Brooks, it

was impossible in the scope of a single paper to consider the entire field of wire-rope usage, and that side was therefore taken up which it was thought would be most valuable to engineers; the author being fully aware of the fact that in treating the matter of stresses there would come requests for information of a practical character as to their effect and different conditions governing installations, which might perhaps at some future time serve as the subject of an additional paper.

Mr. Hymans discusses the author's formula for strength of strand ($W_s = S + 6\,S \cos\theta$) on the basis that the elongation of the strand is equal to the elongation of the center wire. This is not true. What actually happens when the strand is tested to destruction is that the elongation of the wires comes into play, and the difference between all of the wires having absolutely uniform load, theoretically speaking, and the actual condition of test is very slight.

For example, the author has made numerous tests on strands of this character and has obtained efficiencies not only equal but sometimes in excess of those shown by the formula. Similar tests have been made not only with 7-wire strands but also with 19-, 37- and 61-wire strands. The explanation of this is that there is sufficient elongation in the various wires composing strands to absorb slight differences such as those referred to by Mr. Hymans, which do not affect the material result by an appreciable quantity. For instance, assuming a wire having an elongation of 6 per cent to be placed in a 7-wire strand, the difference in length between the inside or center wire and 6 surrounding wires would be about 1 per cent. In a direct pull, therefore, the difference in load between the center wire and the 6 surrounding wires could not exceed 1 per cent. This would mean that 0.06 per cent less elongation would be required on the center wire than on the 6 surrounding wires in order to have a condition so that all 7 wires would theoretically break at the same instant. This is a uniformity of material, however, closer than it is possible to secure, because in normal manufacture wires would vary in elongation anywhere from 6 to 8 or 9 per cent. We need not therefore take into account any small variation in our theoretical calculations which is entirely wiped out or offset by the greater variations in the materials with which we are dealing.

In the case of the strands just mentioned, it would be impossible to choose 6 wires with an elongation of exactly 6 per cent and one wire with exactly 5.94 per cent. We would get wires on which continuous tests with the same wire would show variations anywhere from 6 to 8 per cent, based upon a length of 10 in.

The matter referred to by Mr. Hymans, therefore, is of a similar character to a differential of the second order as compared with a differential of the first order in calculus, where it is always customary to drop differentials of the second order.

This and other points in regard to rope and strand matters might be dwelt upon at length sufficient to fill an entire volume without, however, materially affecting the results obtained by the formula as given in the paper.

In the development of the formula given in the paper the factor C is evidently what Mr. Hymans does not understand. This is a numerical factor. For instance, if a rope is working on a factor of safety of 10, the load due to acceleration is double and the factor C is 1. In other words, C represents unity under this condition. For other conditions it represents a value greater or less than 1, depending on whether the acceleration producing the stress is greater or less than the assumed value.

When a load is hoisted vertically, energy is required in excess of the amount of the dead load. The amount of this energy depends upon the speed. The greater the acceleration, the greater the amount of energy expended and the greater the pull of the cable during the lifting.

Mr. Hymans submits a proof by a different method that the deductions arrived at by the formula are incorrect and utterly wrong. He asks the question, When is the system to receive the acceleration a? Immediately after Formula [**11**] in the paper it is stated that if t is unity the acceleration will be $8.02\sqrt[3]{C}$. The acceleration, therefore, is for one second. As a matter of fact, this formula and the deductions therefrom have been checked by practical application to a number of mine-hoisting operations where ropes have broken in two due to the acceleration factor, and the results have shown that the figures given are correct.

It is unnecessary to enter into an extended discussion of Mr. Hymans' comments except to say that a moving body when brought to rest suddenly expends an energy equal to $mV^2/2g$. The same energy in pounds is expended when a load is lifted quickly under velocity V. The tables given are based upon uniform acceleration of certain stated amounts per second. Table 1 shows the effect upon a rope having no elongation. Table 2 shows the amount of extension which various lengths of rope have, using an increase of load equal to unity. The effect of this extension is to reduce and partially neutralize the stress due to acceleration.

Mr. Hymans further asks, What is the conception or definition of modulus of elasticity of a rope? No difference in definition is necessary between the modulus of elasticity of a rope and that of bar steel or any other similar material. This conception of rope is not entirely new, because there are some cases in technical literature where it can be found. I would refer Mr. Hymans to a book known as Die Drahtseile (The Wire Rope), by Joseph Hrabak, published in 1902, in the seventh chapter of which will be found results of tests of modulus of elasticity.

Tests have also been made by various universities and engineering schools, including the University of Illinois and the Worcester Polytechnic Institute, along with numerous tests by the author, so that there is no more reason for doubting the modulus of elasticity of a wire rope than there is for doubting Young's modulus on solid steel or any other metal. Further comments upon this conception would seem unnecessary.

Mr. Hymans refers to Formula [17] and asks for a fundamental conception. If a strand is composed of several layers of wires, each one possesses its own modulus based upon the angle of lay. If the angle of lay is uniform for all layers, then there is one modulus for the entire strand. Formula [17] is arranged to take into account any difference that there might be in a strand due to different angles of lay, so that an average modulus of the entire strand can be obtained. The same is true of Formula [19], which applies to compound rope instead of a strand.

Mr. Hymans now refers to the matter of the formula for bending stress in a rope, namely, $S = E_r d/D$, and in his discussion brings in the modulus of shear. The conception of bending brings up the question of tension or compression, but not of shear, as it will be readily understood by all engineers. In this connection Hrabak's book also contains information in support of the conception for bending already referred to, and in rope, as in any other material, we must consider facts as they are and not perhaps as we would like to have them. No greater variation in modulus of elasticity of rope exists for any definite construction than exists in plain steel for the value of Young's modulus.

Mr. Hymans brings in the question of the elongation of rope wire in connection with the elongation of rope. Arriving at the modulus of elasticity within the elastic limit, no permanent elongation takes place in a single wire and no permanent elongation takes place in a rope for the same reason. Hence the question of elongation does not

have a bearing upon the question of modulus of elasticity. A piece of steel on a test will return to its original position. A piece of wire cable will also return to approximately its original position if tested within the elastic limit of the material, the only difference being that owing to a slight compression of the hemp center on the heavy loads, there will be a slight permanent set. Repeated tests, however, will not increase this set but will leave the modulus as originally determined.

No. 1681

THE LARGE STEAM TURBINE

By J. F. Johnson, Pittsburgh, Pa.
Member of the Society

The development of the large steam turbine, which has taken place within recent years, is largely attributable to the rapid growth of the electric-power industry, and the records of performance of fourteen turbines varying in capacity from 30,000 to 70,000 kw. which the author presents and which cover a period of four years, are accordingly of interest in showing the reliability of such large units and exceedingly valuable as evidence of the service to be expected.

The design of such large units naturally presents many problems, and those relating to steam areas, rotor speed, blade proportion, number of stages and rotor dimensions are dealt with by the author at some length. The construction of such large units also involves many problems, and those dealing with exhaust chambers, cylinders, bearings, oil-circulating and cooling systems, couplings, etc., are briefly discussed.

THE remarkable growth of the electric-power industry during recent years has been paralleled by an equally remarkable development of steam-turbine-driven generating units. So rapid has been this development that frequently before the first machine of a new design was completed another of materially greater capacity and higher efficiency was being designed.

2 While machines of 15,000 kw. capacity were put into operation as early as 1908, their use did not become general until 1913; and yet today nearly every one of what may be called our large generating stations has at least one unit of 30,000 kw. capacity or larger.

3 Has this growth been natural and healthy, or has it been forced? Will the tendency be toward larger units or will a reversion to smaller sizes occur? If such reversion occurs, will it be the result of faulty engineering, born of overconfidence on the part of the builders or users of the apparatus, or because units of 30,000 kw. and larger are too large for the present and immediate future requirements of our large power-generating stations?

Abstract of a paper presented at a meeting of the Philadelphia Section of The American Society of Mechanical Engineers, November 26, 1918.

4 In our chief industrial centers the electric-power industry has attained its broadest development. Here the appeal of "Do It Electrically" has gained a universal response. As a result power consumption per unit of area has reached high values and this has encouraged the formation of large public-service companies, both by means of development and by means of consolidation of smaller ones. Moreover, a careful analysis of the present applications of electric power will not disclose a likelihood of serious decrease in any of them. On the other hand, there are many applications in which marked future growth seems certain. Important among these are the separation and purification of metals, the use of the electric furnace in metallurgy, and the electrification of our present steam railroads. There can be no doubt that the electric-power industry is today only in the midst of a rapid and healthy growth.

5 In designing machines of large capacity, the selection of the number and sizes of units in a station of given capacity is most important since this selection materially affects the total cost of power generated. If the sizes of units be too small, the cost per kilowatt of the completed station will be greater, the maintenance and operating expenses higher, the efficiency lower, and the reliability at least no greater than if the proper sizes are used. On the other hand, if the units be too large, the cost per kilowatt installed may be too great because of the greater reserve capacity required, and the efficiency may even be lower by reason of the units operating at loads too far below their points of best efficiency.

6 Take for example a district with a maximum peak requirement of 600,000 kw. To insure proper reliability it is decided to generate in three stations of approximately equal sizes. Assume that these stations will normally always operate in parallel and that there will be one spare unit for each five in service during the peak. If 20,000-kw. units were used, there would be 30 operating and six spares, a total of 36 units, 12 in each station. If 30,000-kw. units were used, there would be 20 operating and four spares, a total of 24 units, eight in each station. If 40,000-kw. units were used, there would be 15 operating and three spares, a total of 18 units, six in each station. If 60,000-kw. units were used, there would be ten operating and two spares, a total of 12, four in each station.

7 If, in order to remove from this consideration of ideal size of units conditions imposed by the design of the apparatus, it is assumed that, irrespective of the size, the reliability, efficiency, and purchase price per kilowatt will be the same, then the best results are to be

expected with either the 40,000- or 60,000-kw. sizes, because the installation and operating costs would be less per kw.; the efficiency higher because of the higher efficiency of the larger units; and the reliability greater because of the smaller number of operations of starting and stopping and cutting in and out of service of units necessary.

8 In so far as conditions affected by the design of units are concerned, it is quite generally appreciated that in sizes up to at least 30,000 kw. capacity higher efficiency at the same cost per kilowatt is obtainable purely by reason of the larger size, and a still higher efficiency for a slight increase in cost per kilowatt; and it has been quite conclusively demonstrated that as high a degree of reliability is obtainable in these larger units as in the smaller ones. Fig. 1

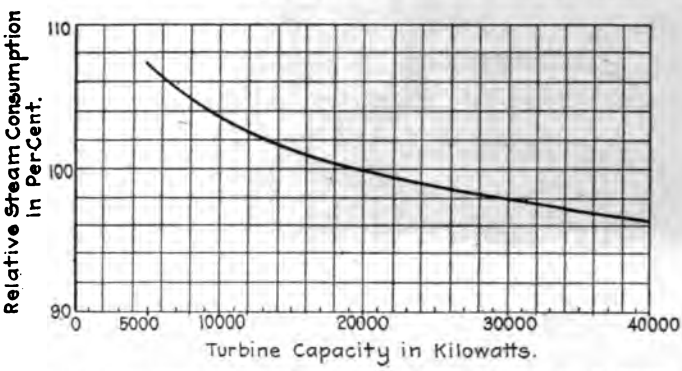

FIG. 1 RELATIVE STEAM CONSUMPTION FOR UNITS OF VARIOUS CAPACITIES DESIGNED FOR EQUAL COST PER KILOWATT

shows the approximate relative steam-consumption rate of units varying from 5000 kw. to 40,000 kw., but all designed for the same cost per kilowatt.

9 Appreciating the need of generating units of large capacities in the future growth of the electric-power industry, the engineering staff with which the writer is associated took up several years ago the work of designing such machines, assured themselves of their feasibility, and advocated their use. A number of them have been in operation several years, and their expected excellence as to reliability and efficiency has been fully verified.

RECORD OF PERFORMANCE OF LARGE TURBINE UNITS

10 Up to the present time 14 units have been sold, varying in capacity from 30,000 to 70,000 kw. maximum. Of these 10 have

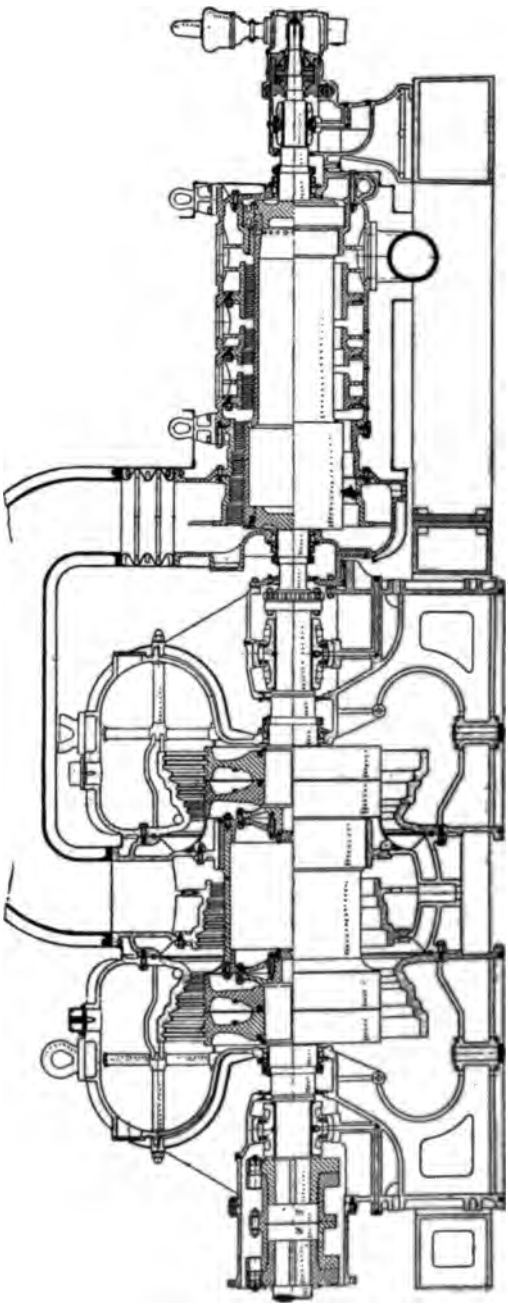

FIG. 2 30,000-KW. TANDEM-COMPOUND REACTION TURBINE, COMMONWEALTH EDISON CO., CHICAGO

een placed in service and seven of them have been in service for eriods varying from 1 to 5 years. The record of these machines in peration should emphatically remove any doubt as to the commercial possibility of units of large capacity, and satisfactorily prove hat at least within limits not reached, increase in size need not npair reliability, and may improve efficiency.

11 The first three of these units, which are exact duplicates of ach other, were sold to the Interborough Rapid Transit Company of New York. They are of the two-cylinder, cross-compound, pure eaction type, 30,000 kw. maximum rating with point of highest fficiency at 25,000 kw., operating with 205 lb. steam pressure, 120 eg. fahr. superheat and 29 in. of vacuum referred to 30 in. The igh-pressure cylinder operates at 1500 r.p.m. and the low-pressure t 750 r.p.m.

12 The first one was put in service December 30, 1914, the econd in February and the third in August 1915. Very elaborate nd exact steam-consumption tests were conducted by the purchaser n the first of these units.[1]

13 These units have been operating on an average of from 16 to 0 hours per day, on fluctuating railway loads of from 10,000 to 0,000 kw. With the first and third no trouble has been experienced nd they have been ready at all times for any service within their esigned capacity except during periods of inspection. In the case f the second the labyrinth packing on the balance pistons of the high-ressure element has failed three times, requiring renewal of some arts. The cause of these failures was supposed to have been nproper adjustment, but investigations following the third failure ndicated excessive lost motion in the thrust bearing and heavy disortional stresses due to rigid bracing of the steam pipe near the urbine as the probable causes.

14 The fourth unit, placed in operation in the Northwest Station f Commonwealth Edison Company, Chicago, in September 1917, onsists of a tandem-compound pure reaction turbine, direct-onnected to a single generator. It has a rating of 30,000 kw. with n overload capacity of 500[illegible] kw., operating with 220 lb. steam ressure, 200 deg. superheat, 29 in. of vacuum, 1200 r.p.m. (See ig. 2.)

15 A few hours after being put into service, subsequent to comletion of erection, the labyrinth packing on the low-pressure element

[1] See paper by H. G. Stott and W. S. Finlay, Jr., Trans.Am.Soc.M.E., vol. 3, p. 655.

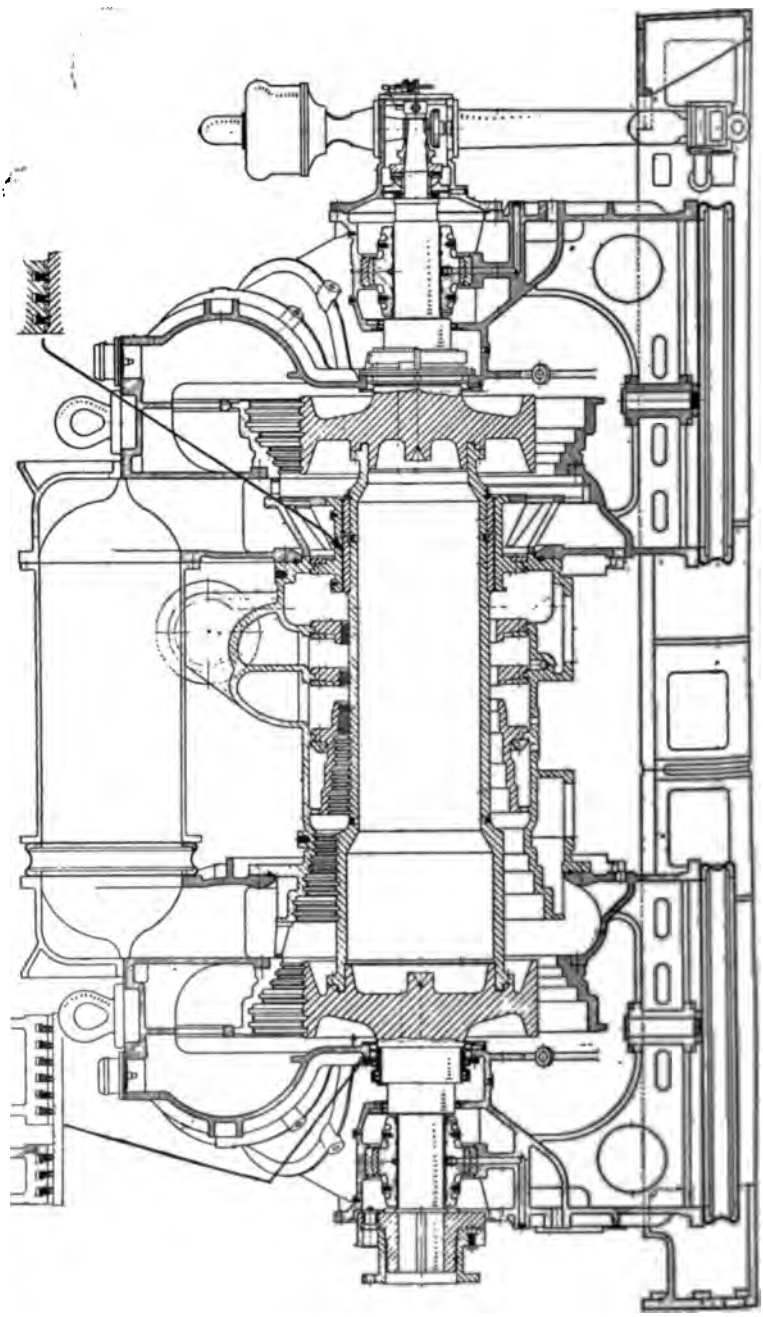

FIG. 3 30,000-KW. SINGLE-CYLINDER REACTION TURBINE, EDISON ELECTRIC ILLUMINATING CO., BROOKLYN

failed, due to buckling of the turbine cylinder, caused by rigid piping connections between the two surface condensers which were bolted rigidly to the two exhaust openings on the turbine and thus prevented the condensers from translating with the turbine as its temperature increased. Temporary repairs were made locally and the unit put in service in about four weeks. It has been operating almost continuously since, carrying loads as high as 40,000 kw. In one instance it was kept on the line for 71 days and then taken off only in order to clean the condenser. Material for making permanent repairs to the labyrinth packing was shipped to the station within a few months after the accident, but the purchaser has not yet given permission to take the unit out of service long enough to install it.

16 The fifth unit, a 30,000-kw., pure reaction, single-cylinder machine, operating on 200 lb. steam pressure, 100 deg. superheat, 29 in. vacuum, was placed in operation in the Gold Street Station of the Edison Electric Illuminating Company of Brooklyn, in October 1917. Owing to congestion in the shops and urgency of shipment, this turbine was not operated prior to shipment. The overspeed test was made after installation. No correction of balance was necessary, and with the exception of a few leaks in the oiling system, and the breaking of a defective gear on the oil-pump drive, no trouble of any sort has been experienced. It has been available for service at all times and has been operating approximately continuously, except over Sundays and when necessary to clean the condensers, at average loads of approximately 23,000 kw., and peak loads as high as 32,000 kw. (See Fig. 3.)

17 The sixth unit, placed in service in December 1917 in the Kent Avenue Station of Brooklyn Rapid Transit Company, is a duplicate of the fifth machine. Immediately after its installation a rebalancing of both turbine and generator rotors was necessary. After having been in service approximately 10 months, the thrust bearing overheated and wiped some, but did not damage any other part of the machine. When opened for inspection it was found that the labyrinth packing strips, which were made of an aluminum alloy, were considerably corroded by the action of strong alkalies used at this plant for treating feedwater; and two rows of blading in the high-pressure portion of the machine were found to have been damaged at some previous time, probably by foreign matter or a defective blade.

18 The seventh unit is a 40,000-kw., 60-cycle, cross-compound machine, installed in the Brunot's Island Station of the Duquesne

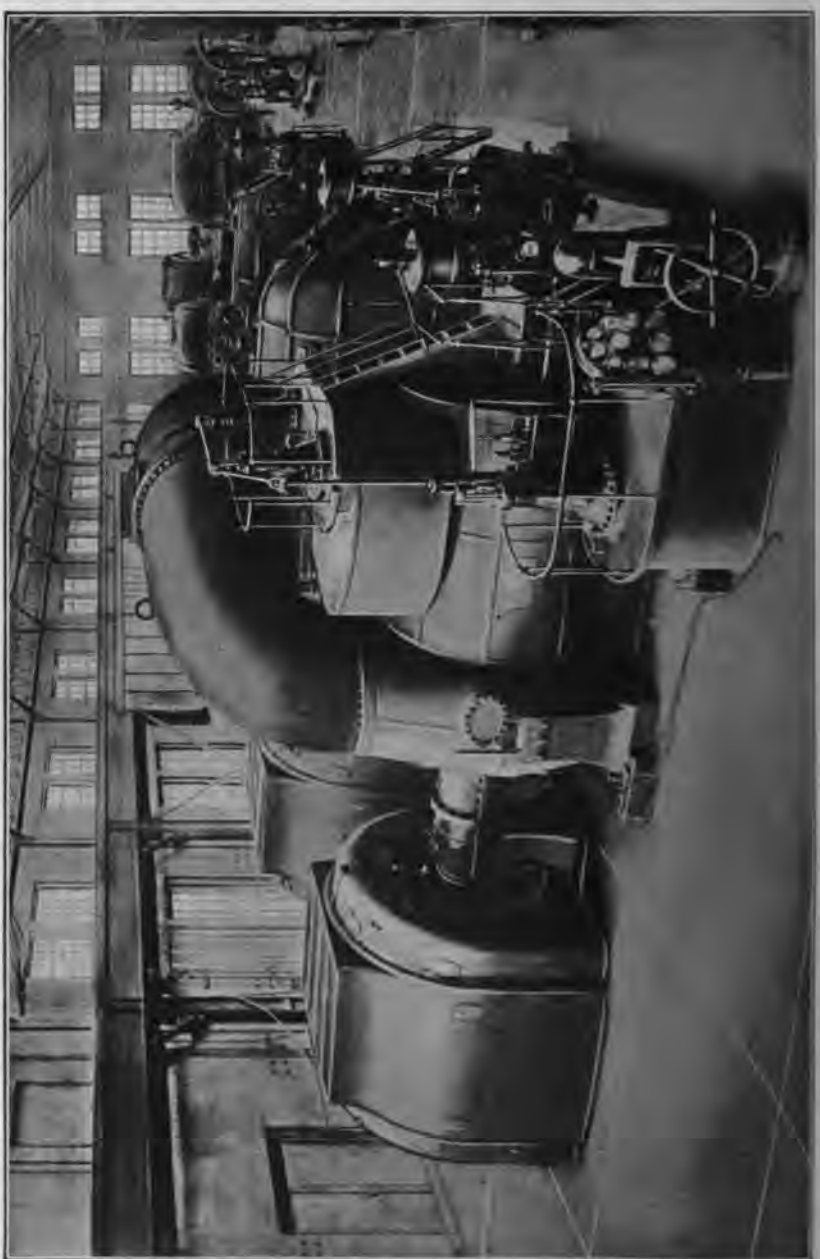

FIG. 4. 30,000-KW. CROSS-COMPOUND TURBINE AND GENERATOR, DUQUESNE LIGHT CO. BRUNOT'S ISLAND STATION

Light Company, and placed in service in December 1917. (See Fig. 4.) The high-pressure element of this machine operates at 1800 r.p.m., and the low-pressure at 1200 r.p.m. This unit has been in regular service carrying loads normally of from 30,000 to 40,000 kw. and peaks as high as 50,000 kw. On February 18, 1918, while operating the machine to correct the balance of one of the generators, the main bearing at the coupling end of the high-pressure turbine burned out, apparently due to interruption of oil service to that bearing. This let the spindle down sufficiently to cause rather heavy blade rubs throughout the machine. The bearing was rebabbitted and the machine put back into service without any other work being done except rechecking the clearances and placing a balance weight on the spindle to correct for the weight rubbed off the blades.

19 In July the generator was damaged by electrical trouble, and while this repair was being made both elements of the turbine were dismantled. The high-pressure rotor was returned to the shops and the damaged blading replaced and rebalanced. New blading was also installed in the stator to restore original clearances and original efficiencies. Inspection of the low-pressure element revealed several broken blades which had slightly damaged the rest of the blading in their rows, requiring replacement of approximately 1½ rows of blading on each end of the machine.

20 The eighth unit, practically a duplicate of the seventh, rated at 45,000 kw. maximum, was placed in service for the Narragansett Electric Light Company in Providence in January 1918. In placing this machine in service the labyrinth packing on the high-pressure was damaged, due to improper adjustment, which necessitated temporary repairs, keeping the machine out of service until about March. Since then no trouble has been experienced except some distortion of the couplings caused by a series of violent short-circuits. Permanent repairs to the labyrinth packing have been made and n coupling parts are to be installed in the near future. In the meantime the old parts are operating satisfactorily without any evidence of distress. This machine operates on loads as low as 5000 kw., and has carried a peak load of 50,000 kw. for periods of from four to five minutes.

21 The ninth unit is a 70,000-kw., three-cylinder, cross-compound, 25-cycle machine, installed for the Interborough Rapid Transit Company in New York. The one low-pressure element was placed in service April 18, 1918, operating on high-pressure steam. The high-pressure element was placed in service August 21, operating

inlet valves). It leaves the last stage at 380 cu. ft. per lb. when 28½ in. is maintained by the condenser, and 550 cu. ft. per lb. when 29 in. is maintained; that is, the volume when exhausting to 28½ in. vacuum is 166½ times, and when exhausting to 29 in. is 241 times as large as it is at the entrance. This means that if the rate of steam flow be such as to require an 18-in. steam-inlet pipe, and if its velocity be maintained the same through the exhaust as through the inlet pipe, then, when expanding to 28½ in. vacuum the exhaust opening will have to be 19 ft. 4 in. in diameter, and when expanding to 29 in. vacuum 23 ft. 4 in. in diameter. If, further, the mean diameter and exit angle of all the rows of blading be the same and the ratio of blade speed to steam speed be the same in each, thereby keeping the theoretical efficiency of all stages equal, and if these blade and steam speeds be so chosen as to fix the height of blades in the first stage at one inch, the last row will have to be approximately 13 ft. 10½ in. if designed for 28½ in. vacuum, and 20 ft. 1 in. if designed for 29 in. vacuum. The impracticability of adhering to such proportions in actual designs is obvious.

29 *Rotor Speeds and Blade Proportions.* Here is where the combining of conflicting factors begins. In the first stages the areas and blade heights should be kept large in order to reduce the losses, and in the low-pressure stages they must be sacrificed on account of practicable limits of mechanical design. In single-cylinder machines where the blading is all on the same spindle, the problem becomes doubly difficult.

30 The first determination is that of rotative speed, which is usually not difficult to make since the frequency of the generator restricts the permissible speeds to a few and these are rather widely separated. The limiting capacities at the various permissible rotative speeds for which generators can be built must also be considered, although at the present time the practicable limits of turbines and generators are reached at approximately the same capacities except in the case of single-phase generators. With these the limiting capacities are very much less than with polyphase generators.

31 The chief factor in the selection of the rotative speed is the design of the last row of blades with reference to height, diameter and exit angle, because this is the most important stage in the entire turbine. In it the mechanical stresses and fatiguing effect of vibration, the B.t.u. drop, and physical dimensions, are all greatest. Consequently, upon it depends largely the reliability, efficiency, and cost of the unit.

32 Here must be considered the alternatives of a higher rotative speed with the low-pressure stage made multiflow as against a slower rotative speed and single-flow construction. The length of blades must not be excessive with reference to the diameter, not only because of the higher stresses in the blades and rotor, but also because the difference in velocity in the blades and their tips and at their roots, as well as the difference in blade spacing, will, if too great, materially impair the efficiency.

33 On the other hand, if the area through the blades be restricted, the steam velocity will become too high and the bearing losses too great. If this restriction is carried to the extreme, the steam in passing through the last row of blades may reach its critical velocity without expanding entirely down to the condenser pressure, in which event the remainder of the expansion takes place in the form of an explosion upon leaving the blade passages, and from it only a small percentage of the energy is recovered.

34 In order, therefore, to secure the most satisfactory design for the last stages, and to permit the stresses or physical dimensions with the ever-present cost from becoming prohibitive, several compromise features should be employed.

35 The first of these consists of increasing the rotor diameter and blade heights until the safe limit of stress is reached, keeping the blade height within approximately one-fourth of the rotor diameter as a limit of good practice. The materials of which the rotor and blades are made will of course determine the safe stresses, and on account of the great import of safety and reliability in these parts, only good quality of plain or 5 per cent nickel low-carbon steels should be used. These are commercially common materials, uniform in quality and do not require sensitive heat treatments.

36 For rotors, cast or forged steel having a tensile strength of 70,000 lb., true elastic limit of 28,000 to 30,000 lb. and elongation of 18 per cent in 2 in. may be stressed to 20,000 lb. per sq. in., and for blades, 5 per cent nickel steel having a tensile strength of 85,000 lb., and true elastic limit of 35,000 lb., may be stressed to 25,000 lb., both at 20 per cent overspeed. The stresses at normal operating speed will therefore be 13,900 and 17,350 lb., respectively, and the factor of safety against rupture approximately five.

37 Increasing the diameter not only permits increasing the blade height but also the steam speed without materially affecting the efficiency, by reason of the increase in blade speed. There is, however, a slight falling off in efficiency with the higher speeds even

though the ratio of blade speed to steam speed be kept practically constant, because the actual velocity of the steam with reference to the blade being greater, the frictional losses will be greater.

38 The second compromise consists of increasing the steam-passage area through the blades by changing the blade shape. This change increases the angle between the direction of steam flow from the blade and the direction of the blade, and a slight impairment of efficiency results. However, this loss is slight compared to the gain from the higher ratio of blade speed to steam speed resulting from the increased area. This practice is standard on practically all condensing machines built for high vacuum.

39 *Multiple Stages.* The third compromise consists of permitting the steam speed to increase without a corresponding increase in blade speed, thereby decreasing the ratio of blade speed to steam speed and increasing the leaving losses. This compromise may properly be employed up to the point where the loss of efficiency will justify the increased expense of greater blade areas which may necessitate dropping to a lower rotative speed, or employing multiple stages.

40 Two or more low-pressure stages in multiple in connection with a single high-pressure stage are used when the required areas cannot be obtained with a single stage at the rotative speed chosen, and when it is more feasible to employ multiple stages than a lower rotative speed. Other considerations favoring multiple stages are reduced physical dimensions of the exhaust chambers, thus simplifying both the ribbing and bracing necessary to maintain the proper rigidity and eliminating difficulties incident to shipping large units.

41 The design of the higher stages usually involves only an equitable selection of diameters, blade speeds, and steam speeds. Keeping these low results in low stresses and high efficiency but a large number of stages and high cost; while keeping them high reduces the length, weight and cost, but increases the stresses and impairs the efficiency.

42 If the steam volumes in the first stages are relatively small for the rotative speed employed, as would be occasioned by the use of high steam pressure or low rating, a double velocity-stage impulse element may often be employed to advantage; the advantages secured being reduction of length, increased diameter, reduced pressure and temperature inside the main cylinder, and adaptability for varying overload capacity, but not increased efficiency nor decreased cost.

43 *Rotor Proportions.* Having fixed the rotative speed to secure proper design of the low-pressure stages, and the diameters and steam speeds of the high-pressure stages to give the highest economy, the length of the rotor may become excessive, necessitating its division into two parts in order to maintain requisite reliability. These parts mays be arranged either in tandem form, driving a single generator, or in cross-compound form, driving two generators. When arranged cross-compound it will often be found advantageous to increase the rotative speed of the high-pressure element, thus gaining reduced physical dimensions, weight and cost without sacrifice of efficiency or reliability. The multi-cylinder construction is especially desirable in the employment of high steam pressures and superheats in that the high-pressure turbine structure is small and there is no danger of stress complications resulting from wide temperature differences and no transmission of heat through the cylinder walls from the high-pressure to low-pressure stages. It has a further advantage in these days of increasing steam conditions since a unit may be designed for given steam conditions and later redesigned for materially higher conditions, the redesign being carried out entirely in the high-pressure element.

44 In units of 60,000 kw. or larger the three-cylinder cross-compound construction employing one high-pressure and two low-pressure elements possesses the advantages of high efficiency and reliability without employing excessively large structures, and has greater flexibility than is possible with either of the other constructions. This flexibility, enabling the high-pressure element to operate with either low-pressure element, or either of the three elements to operate alone, admirably adapts it for use in systems not yet large enough to permit employing a single unit of such large capacity. These units may be provided with a control mechanism by means of which either of the elements may be taken out of service either automatically or manually, and the remaining ones carry loads up to the maximum ratings of their generators. The low-pressure elements, when operating on high-pressure steam direct, may be made to carry loads for short periods considerably in excess of the rated capacities of their generators.

CONSTRUCTION DETAILS

45 Reliability and general operative excellence of large turbines are largely dependent on the excellence of design of details such as the blading and blade fastenings, provisions for maintenance of clear-

ances and alignment under all possible variations of operating conditions, bearings and oiling system, control mechanism, glands, couplings, and protective devices against overspeeding. The standard practice with regard to these as applied to all large units built by the company with which the writer is connected will be here given.

46 *Blading.* All low-speed reaction blading in which the stresses do not exceed about 15,000 lb. per sq. in. at 20 per cent overspeed are made of a special bronze composed chiefly of copper and a small percentage of tin and phosphorus. Upon the base of each blade a foot is forged, and the cross-section of the blade near its base taperingly increased, adding approximately 40 per cent to its area at the point of attachment. These blades are installed in double dovetail grooves by means of specially constructed spacers or interlocking pieces, the spacers being locked in the groove and the feet of the blades locked underneath the spacers. In larger sizes where it becomes difficult to drive up the blades and spacers tight enough to insure perfect fitting between the parts and perfect filling of the grooves, compound side wedges are employed to secure the requisite tightness.

47 The chief destructive element of all blading is vibration caused by the flow of steam and by vibration of the entire rotor when operated under conditions of defective balance or alignment. The thickening of the blade section near its base serves to very considerably reduce the amplitude of its vibration and to prevent concentration of deflection with its attendant crystallization at the point of attachment, where the ordinary blade is weakest. Blades for higher speeds, in which the stresses may go as high as 25,000 lb. per sq. in., are drop-forged of a very pure electric-furnace iron containing about 5 per cent of nickel. They are installed in grooves as shown in Fig. 6.

48 The spacers are made integral with the blades, and compound side wedges are used to insure a tight fit at the top of the groove and protect the reduced portion of the blade foot against vibrational stresses. Impulse blading when used is installed in the same manner. All blades are lashed together to minimize the vibration and maintain uniform spacing. Blades up to 4 in. in height have a single lashing near the top, from 4 in. to 12 in. two, and those above 12 in. three.

49 A proper design of the turbine stator so as to insure maintenance of clearances and alignment under all possible variations of operating conditions, such as reduction of steam pressure and total

or partial loss of superheat or vacuum, is difficult but essential. In such large structures the amount of expansion and contraction due to temperature changes is considerable, and usually occurs simultaneously with important stress changes caused by varying stage pressures; consequently there is no friction of rest to overcome and a comparatively slight uneven temperature change or unbalanced stress will cause a distortion.

FIG. 6 METHOD OF INSTALLING HIGH-SPEED BLADES

50 *Exhaust Chambers.* The introduction of high vacuum, bringing with it large diameters in the low-pressure stages and enormous exhaust chambers, necessitates a considerable amount of carefully devised ribbing and bracing in order that the bearings supported in the exhaust chamber structures will under all conditions remain concentric with the stationary blade- or nozzle-carrying elements.

51 Fig. 7 shows such reinforcing. Cast-in braces when employed are always provided with an open joint which is made up after the

rough machining and annealing have been done, thus avoiding all distortional stresses.

52 *Cylinders.* The main cylinder castings are made as plain, simple and symmetrical as possible, and the blade-carrying elements are almost invariably cast and finished separately.

53 The turbine cylinder is always supported on the bedplate by means of chairs or pedestals engaging it as near the center line as possible, and independent of temperature changes caused by varying load or operating conditions. The steam chest and throttle valves are supported on springs so as to move freely with the turbine, con-

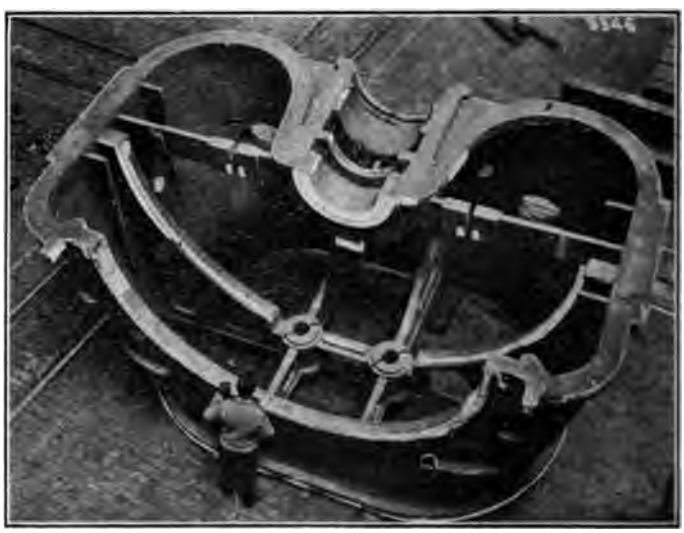

FIG. 7 RIBBING AND BRACING OF LOW-PRESSURE CHAMBER

sequently the alignment of the main turbine and generator bearings is not affected by these changes.

54 *Bearings.* Practically every turbine element contains three bearings: two to support the rotor and one to maintain the longitudinal alignment. The supporting bearings consist of heavy cast-iron shells lined with babbitt and split horizontally to facilitate removal. They are so bored that for two-thirds of the circumference the minimum clearance between the bearing and journal is approximately 0.020 in., the journal being normally supported and guided by less than the lower third of the bearing circumference. This large clearance reduces to a minimum the power lost and heat generated in

the bearing. The journal speed is not allowed to appreciably exceed 100 ft. per sec. nor the pressure 100 lb. per sq. in. of projected area. A sufficient quantity of oil is supplied through a longitudinal groove in the top of the bearing to provide both lubrication and cooling; consequently no water cooling of the bearings is necessary. The oil pressure normally carried on the bearings is 5 lb. gage, although they will continue to operate satisfactorily as long as the oil supply is sufficient to keep the oil groove filled without any pressure whatever. The bearing is of course self-aligning, being provided with four large spherically machined pads (one each at the top, bottom and either side) which fit a spherical supporting ring in the housing. Underneath each of the four pads several sheet-steel liners of varying exact thicknesses are placed to enable easy and accurate adjustment of alignment. For example, to change the alignment 0.010 in. either vertically or horizontally a 0.010-in. liner is taken from underneath one pad and placed underneath the opposite one.

55 The alignment bearing is of the Kingsbury type, modified in detail design to best serve the requirements of the turbine upon which it is employed. This is believed to be the most perfect form of bearing yet devised for the purpose.

56 *Oil-Circulating and Cooling System.* The oil-circulating and cooling system maintains an ample supply of oil at approximately 60 lb. pressure for operating the governor-controlled valve mechanism, in addition to supplying all bearings at approximately 5 lb. pressure. It is designed with special reference to positive circulation, effective cooling, straining, and settling for separation of foreign matter or impurities, accessibility for thorough cleaning and longevity of the lubricating qualities of the oil. It consists of a cooler, strainer box, settling and separating reservoir, direct-driven pump, and a separate steam-driven auxiliary pump, together with the necessary piping. It ordinarily has a capacity of approximately 1000 gal. The oil flows by gravity from the settling reservoir into the oil pump from which it is delivered under 60 lb. pressure to the valve-operating mechanism, thence to the oil cooler, bearings, strainers, and back to the reservoir. A spring-loaded valve located close to the valve-operating cylinder bypasses the surplus high-pressure oil direct to the oil cooler. Units in which a considerably greater quantity of oil is required for lubrication than for operating the valve gear are provided with double pressure pumps to reduce the power required, and the stress on the oil. Under normal operating conditions the maximum temperature of the oil is from 140 to 150 deg. fahr.

57 The oil cooler is built along the lines of an ordinary surface condenser and employs regular straight condenser tubes. Every part, including the inside and outside surfaces of the tubes, is readily accessible for thorough cleaning so that the original efficiency of the cooler may be restored at every cleaning. The cooling water makes a sufficient number of passes to raise its temperature close to that of the oil so as to decrease the quantity required.

58 The strainer box contains three strainers of different meshes which may be removed and cleaned while the unit is in service. If they are allowed to become choked up, the oil will overflow them without interrupting the circulation.

59 The reservoir is designed to cause impurities and foreign matter to settle to the bottom from whence they cannot get into the oil-pump suction, but may be drawn off either manually or automatically to a filtration system.

60 The oil pump is of the reciprocating-plunger type, direct-driven from the main governor spindle, and is accessible for inspection or repairs without complete removal from the turbine.

61 *Governing Mechanism.* Since constant voltage and frequency are insisted upon by public-service companies, good governing of a turbine unit becomes important. The governing mechanism must be extremely sensitive, positive, and quick to adjust itself to small or large changes in load and at the same time rugged, reliable, and unaffected by such variations as occur in ordinary wear and care. For these reasons the following several features of design are employed.

62 On account of the power required to operate the large valves, some form of fluid-pressure relay mechanism is necessary. For this the regular turbine lubricating oil under suitable pressure has proven most satisfactory.

63 The governor, which is of the flyball type, is made very large and powerful so that it can control the oil relay valve with ease and accuracy. It has a minimum number of moving parts and is made as frictionless as possible by the employment of hardened knife-edge bearings in all connections between the weights and clutch. It is driven from the main turbine rotor through worm and wheel gears at a speed of approximately 300 r.p.m.

64 Unavoidable inaccuracies in machining of the oil relay control valve, friction and lost motion in the governor and valve linkage, and inertia of the operating fluid are the chief obstacles to good regulation, since the speed must change sufficiently to move the

governor weights far enough to overcome all these before there will be any response from the valves, and when they do move they will probably overtravel. These difficulties have been overcome by giving the linkage, adjacent to the governor, a small positive oscillating motion, sufficient to overcome any reasonable lost motion and inaccuracy of the relay control valve, and still cause a very slight oscillation of the main inlet valves. The oil relay control valve and high-pressure-oil bypass valve are placed as close to the operating cylinder as possible, and a positive or constant-volume oil pump is used. The oil flow is therefore continuous in nearly all of the piping to and from the oil-operating cylinder. Consequently the slightest change in speed will be quickly responded to by a proper change in steam flow.

65 *Glands.* To prevent leakage of steam or air where the rotor shaft passes through the casing, combination labyrinth and water glands are used. These constitute an ideal sealing arrangement. They are absolutely tight and permit no leakage of steam, vapor, or water into the engine room. They require no adjustments for varying load conditions, and do not depend upon the operation of any automatic devices. There is no mechanical contact between stationary and rotating parts, and therefore no wear. They are extremely simple in design, require no special attention, and are as durable as any other part of the machine.

66 The simple water gland being ill adapted for operation against high pressures or at speeds very much less than normal, the labyrinth is added to enable establishing a vacuum before starting up, and also to reduce the pressure on the water gland when the pressure against which the gland must seal is high. The operation is very simple. In starting up, high-pressure steam is turned on the labyrinth glands. When about three-fourths speed is reached, the water is turned on and the steam off.

67 *Coupling.* The coupling between the turbine and generator is of a flexible-pin type and has important advantages over the solid-claw type which it replaced. Sufficient elasticity is provided in the pins to distribute the shocks produced by heavy short-circuits and both the pins and bushings are renewable in case excessive wear takes place.

68 Ratchet teeth are machined into the circumference of the coupling flange, in connection with which a barring-over device is employed to turn the rotor for inspection or for connecting or disconnecting the two halves of the coupling.

69 In order to secure the maximum protection against overspeeding, all the steam entering the turbine is made to pass through the primary governor-controlled inlet valve; consequently, if this one valve is kept in proper operating condition it is impossible for the speed to get beyond the control of the governor, regardless of whether or not the overload valves leak or stick. Should either the governor or primary inlet valve become inoperative, a small but powerful overspeed stop mechanism installed in the end of the rotor shaft will come into operation at approximately 10 per cent overspeed, and release the pressure on one side of two small steam pistons which normally have full steam pressure on both sides of them. The resulting movement of one of these pistons will release the main spring on the main throttle valve, causing it to close quickly and the other will admit high-pressure oil to the valve operating cylinder, and close if possible the primary inlet valve.

No. 1682

MARINE PRACTICE IN VALVES AND FITTINGS

By A. G. Christie, Baltimore, Md.
Member of the Society

In this paper the author discusses marine practice during the war in the selection of valves and fittings. The fabricated-ship yard, it is stated, was the chief factor in bringing about the utilization of standard types and sizes, and the scarcity of copper made it necessary to employ steel for piping. Particulars are given of the new types of flanges and fittings adopted, as well as of the progress made in conforming marine valve practice to the A.S.M.E. standards.

THIS paper consists of a series of comments on certain marine practices in regard to valves and piping, from the viewpoint of a central-station man. In recent years there has been a wide use on shipboard of such types of central-station equipment as water-tube boilers and superheaters, geared turbine units, high-vacuum condensers with rotary and ejector air pumps, and centrifugal boiler-feed pumps. Marine practice, however, has lagged behind central-station practice because of the well-known conservatism of ship owners.

2 It has taken this world war to accelerate the adaptation to ships of much of the standard central-station apparatus. Certain factors are now at work which have considerable influence on present marine practice in valves and piping. Of these the greatest is the fabricated-ship yard. In the old-style yard the shops would make up any or all of their fittings or valves to their special designs, each yard having its own designs which differed from those of other yards. The result of this was a constantly increasing number of special valves and types in each shipyard, with the consequent increase in cost of ship construction. The fabricated-ship yard, however, was forced to buy in the open market and in order to get deliveries had to purchase standard types and sizes. This made engineers study their

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valves and endeavor to standardize them. In one yard it was thus found possible to reduce the number of types by 20 per cent. It is entirely practicable to use manufacturers' standard stock patterns for nearly all valves, fittings and auxiliary equipment. This standardization, with consequent reduced costs, will be one of the deciding factors in maintaining our shipbuilding supremacy after the war. Standard valves require fewer repair parts and these are more easily procurable for renewal. Decided advantages may be gained by still further extending present standardization.

PIPING

3 A factor which has influenced piping practice is the availability of materials. For instance, copper piping in sizes suitable for steam mains has become so scarce that open-hearth lap-welded steel pipe is often adopted in its place. The use of copper piping has long been standard practice on shipboard. This piping has considerable flexibility and generally stands up well in marine service, but it is not well adapted to superheat conditions. Steel pipe is much cheaper than copper pipe, is more readily available, and is well adapted to any pressures and temperatures that may be encountered. Some engineers fear that it may lack the flexibility of copper pipe, although steel piping in central stations is frequently subjected to strains from contraction and expansion as severe as one finds on board ship; and furthermore is frequently subjected to severe stresses due to unbalanced turbine rotors and other harmonic vibrations. The substitution of steel for copper piping is merely a matter of marine engineers becoming accustomed to designing and installing their steam systems in accordance with steel-pipe standards. In other words, it is dependent on their ability to break away from traditional practice.

4 Steel pipe, however, does not withstand corrosion as well as copper pipe. Galvanized steel pipe has been tried for this purpose. In time the galvanized material flakes off under the influence of heat and causes trouble. Repeated painting of such steel pipe seems to be the best protection.

5 Galvanized pipe should be used on sanitary systems and bilge and ballast piping. However, no advantage is gained by galvanizing the cast-iron fittings of these systems. It is also questionable whether fuel-oil piping in oil-burning ships needs to be galvanized at all.

6 The problem of caring for expansion has made many engineers prefer copper to steel in piping. In general, long-radius bends provide the best means for taking care of expansion difficulties. Space is limited in vessels, but much may be accomplished in the way of providing such bends if a little study is given to the subject. Some have questioned the flexibility of bends of extra heavy steel pipe. Crane Company's tables indicate that there is usually ample flexibility to care for any lengths that are generally used on shipboard.

PIPE FLANGES

7 Expanded flanges of the Lovekin or similar types are almost universal with copper pipe. Lovekin flanges are used to some extent with steel pipe, but welded or screwed joints are more common.

8 Land practice in piping seems to have advanced far beyond marine practice in the use of the Van Stone joint. It is said that the first installation of this type of flange on shipboard many years ago was not a success. Apparently this has condemned this excellent joint ever since. Although giving excellent service under most exacting conditions on land, it is taboo at sea. The welded type of Van Stone joint now in use in central stations has apparently never been tried out at sea.

FITTINGS

9 With superheated steam, and in general with all steam of over 150 lb. pressure, it is advisable to use cast-steel fittings on the steam lines. For pressures of 100 to 160 lb., extra heavy cast-iron or, better still, semi-steel fittings may be used. For pressures below 100 lb. cast-iron or malleable fittings of standard pattern may be used. In screwed fittings the collar over the threaded portion should be sufficiently heavy to prevent distortion when screwing up with pipe wrenches. Malleable iron is preferred by many on account of its lesser liability to rupture under stress. However, such fittings are generally lighter than cast iron and are sometimes deformed in screwing up.

10 In central stations it is very common practice to find branch outlets welded to the main pipe and in general these welded pipes have given very excellent service. This practice is apparently very little used in marine work, although it would make a weight-saving construction by doing away with many cast-iron special fittings now used.

VALVES

11 Standard types of valves must be bought if one is to place orders in the open market under present conditions. Steel valves are used for superheat. Some shipbuilders even specify steel valves for all boiler pressures of 200 lb. or greater. If superheat is not used the valves may be extra heavy, of cast iron or semi-steel. These materials are also used for auxiliary steam lines. Bronze valves are sometimes employed in the smaller sizes, but these are very much more expensive than the extra heavy cast-iron valves and in sizes of 2½ in. and over have no advantage over them except in lightness of weight.

12 Valves 2½ in. and above must have bolted bonnets to comply with the U. S. Steamboat Inspection Rules. The marine or cross-head type of yoke is much superior to the standard cast yoke for ship purposes. It weighs less and is generally stronger and more readily repaired. It costs very little more than the cast yoke, but is not "standard" with many builders. The latter yoke can be safely used for all low-pressure services.

13 It is customary on board ship to use the screwed-union bonnet on 2-in. and smaller valves. This type of valve is generally more expensive than the ordinary bonnet type, but has many points of superiority such as its regrinding facilities, longer life and less liability to damage when dismantling. Valve manufacturers generally make the screwed-union bonnet valves in two weights, one to withstand 200 lb. pressure, the other for 350 lb. pressure. It is therefore necessary to use the 200-lb. valves for many low-pressure services. This has considerable advantages, for fewer types of valves need be bought and their interchangeability is increased.

14 Cast-iron or semi-steel valves for marine service are usually required to have a solid bronze disk with bronze seat. The stem may be of rolled phosphor bronze, rolled naval brass or manganese bronze. Gland studs and nuts should also be of bronze. Steel valves for superheat generally have monel-metal disks and seats with bronze or nickel-plated steel stems. The bronze generally used for valve bodies, disks, seats, glands, etc., is the navy composition "M" consisting of copper 87 per cent, zinc 7 per cent, tin 6 per cent, and may contain lead up to 2 per cent in place of part of the copper. The lead content must be kept as low as possible on account of the action of the salt water.

15 It is the practice of many marine designers to specify a flange corresponding to extra heavy standard on the sea side of all sea valves,

sometimes even when these are connected to the sea chests. Usually the valve is in all other respects of standard weight. This extra heavy flange adds nothing to the strength of the valve, for its weakest point is in the neck behind this flange, which is sometimes but not always made extra heavy. Some maintain that the extra heavy flange is needed to stiffen the ship plate. This same result is secured elsewhere by adding a reinforcing ring to the ship's plates. This type of valve is a "special" to the manufacturers and hence is high-priced and often difficult to obtain on reasonable deliveries.

16 Shipbuilders generally have endeavored to use A.S.M.E. standards for flanges and drilling. However, some criticisms have been heard. For instance, many marine engineers do not favor the raised faces on extra heavy flanges. They prefer flat faces. The flat faces are also favored for bolting to bulkheads and to other ship plates.

17 The bolting specified for certain sizes in the A.S.M.E. standards has not been satisfactory to many marine designers. For instance, in the 3-in. and 3½-in. standard-weight flanges the A.S.M.E. standard calls for four holes, while many marine designers use six holes. Also, in the 2-in. and 2½-in. extra heavy flanges the marine engineers frequently use six holes where the A.S.M.E. standards specify four. The A.S.M.E. standards increase the holes at one jump from four to eight. There seems considerable justification for the use of the six-hole flange.

18 One cannot help commenting on the small use made of gate valves on ships. These are especially adapted to fuel-oil service and could be used to advantage on many water lines just as in land practice. A greater use of gate valves would relieve the existing valve shortage to an appreciable extent. They also reduce pipe friction. Reducing valves, relief valves, separators, traps, injectors, etc., can all be supplied equally well from the manufacturer's standard stock patterns made for central-station work as from special marine designs.

19 It is rather difficult to understand the basis for marine practice in heating systems. Live steam is usually passed through a reducing valve and supplied to the heating system at 20 to 30 lb. pressure. The advantages of exhaust steam and of steam bled from the main turbine for heating do not seem to be fully appreciated in marine practice. Such uses of steam would make operation less simple, but would result in a thermodynamic and economic gain, especially in passenger ships and troop transports.

20 Inspectors are frequently required to apply tests to valves. In general, such tests are specified in Lloyd's and U. S. Steamboat Inspection Rules. A satisfactory standard for inspectors is to test all high-pressure steam valves under hydraulic pressure to three times their working pressure and to test all other valves to twice the working pressure corresponding to their weight or classification.

No. 1683

ADVANTAGES OF HIGH PRESSURE AND SUPERHEAT AS AFFECTING STEAM-PLANT EFFICIENCY

By Eskil Berg,[1] Schenectady, N. Y.
Non-Member

After pointing out that steam turbines having a thermodynamic efficiency of nearly 90 per cent are available and that this figure permits of but slight increase through improvement, the author gives calculations showing the gains in fuel economy that may be obtained by the use of higher steam pressures and by the application of superheat. He further shows that a combination of both will give the best results and that, assuming a turbine efficiency of 85 per cent, a boiler (oil-fired) efficiency of 88 per cent, 800 lb. pressure and a steam temperature of 800 deg. fahr., the steam process compares very favorably with the results obtained with Diesel engines when it is considered that fuel for the latter is 50 per cent higher in price than that which can be satisfactorily burned under a boiler.

THE advantages of the steam turbine as a prime mover are today too well known to need much discussion. It is, however, interesting to note that in the early stages of the development, when the thermodynamic efficiency was only about 50 or 60 per cent, it still had such great advantages over its competitor, the reciprocating engine, that it rapidly began to take its place. The chief reason for this is, of course, that outside of its mechanical advantages of simple rotation, it could advantageously use steam at the lower pressure ranges, and a vacuum of $28\frac{1}{2}$ in. or higher is now called for as standard by larger central stations.

2 The development of the steam turbine has advanced very rapidly, the designer has constantly had higher efficiency in view, and has in this respect succeeded so that today turbines are in operation that are giving a thermodynamic efficiency of almost 90 per cent. While in the future this already high efficiency may be improved by a small percentage, we will have to look to other features of the power

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plant for further gains in fuel economy. Such gains can be made by increasing the temperature range of the steam, but as the lower range is fixed by the temperature of the cooling water, the gain must be made by going to a higher temperature in the beginning of the cycle, which can be done either by the use of higher steam pressure or by the application of superheat. It will be shown later that a combination of both will give the best results.

3 The thermodynamic or Rankine-cycle efficiency of a turbine is the ratio of the mechanical energy taken out of the steam by the turbine to the total energy in the supplied steam when this steam is expanded adiabatically from the pressure at the throttle valve to the exhaust pressure in the turbine casing. (Adiabatic expansion takes place when the lowering of the temperature of the steam is done entirely by extraction of work from the steam.)

4 The steam consumption of a turbine when connected to an electric generator is generally stated in pounds of steam per kilowatt-hour, and is the amount of steam required to deliver one kilowatt of electrical energy for one hour.

5 "Theoretical water rate" is a term generally used in all turbine investigations, and is the ratio of one kilowatt-hour expressed in foot-pounds (2,654,000) to the available energy in one pound of steam expressed in foot-pounds. The ratio, therefore, between the theoretical water rate and the actual measured water rate gives the efficiency. When the turbine is connected to an electric generator the combined efficiency of turbine and generator is generally given.

FORMULA FOR CALCULATION OF AVAILABLE ENERGY

6 The formula for calculating the available energy of steam expressed in foot-pounds, either dry or superheated, when expanding adiabatically to any back pressure, is seldom found in handbooks or textbooks, and when such an expression is found it is rather complex and difficult to use. The formula can, however, be made very simple when expressed as the difference between the total heat input and the heat left in the liquid together with the latent heat in the mixture at the lower pressure. It then becomes:

$$\text{Available energy in ft-lb.} = 778\,[H_1 + C_p t_1 - (q_2 + x_2 r_2)]$$

where H_1 = total heat of saturated steam at initial pressure p_1
C_p = specific heat of superheated steam
t_1 = deg. fahr. superheat at pressure p_1
q_2 = heat of the liquid at lower pressure p_2

x_2 = quality of the steam at pressure p_2
r_2 = latent heat at pressure p_2.

7 All of these quantities are found in any steam table except x_2 (dryness factor), which is, however, easily calculated from the fact that the entropy is constant before and after the expansion.

8 Entropy of superheated steam is:

$$C_p \log_e \frac{T_1 + t_1}{T_1} + \frac{r_1}{T_2} + \phi_1$$

Entropy of moist steam is:

$$\frac{X_2 r_2}{T_2} + \phi_2$$

By making these equal and solving for x_2 there results:

$$x_2 = \frac{T_2}{r_2}\left(C_p \log_e \frac{T_1 + t_1}{T_1} + \frac{r_1}{T_1} + \phi_1 - \phi_2\right)$$

in which T_1 = absolute temperature at pressure p_1
T_2 = absolute temperature at pressure p_2
ϕ_1 = entropy of water at pressure p_1
ϕ_2 = entropy of water at pressure p_2.

Example. Find the available energy of one pound of steam when expanding from 250 lb. gage pressure, with 250 deg. superheat, to 29 in. vacuum (0.5 lb. abs.).

Available energy $= 778\,[H_1 + C_p t_1 - (q_2 + x r_2)]$

$H_1 = 1202.3$
$C_p = 0.553$
$t_1 = 250$
$q_2 = 48$
$r_2 = 1046.7$

$$x_2 = \frac{T_2}{r_2}\left(C_p \log_e \frac{T_1 + t_1}{T_1} + \frac{r_1}{T_1} + \phi_1 - \phi_2\right)$$

$T_1 = 461 + 406.2 = 867.2$
$t_1 = 250$
$r_1 = 821.6$
$\phi = 0.5739$
$r_2 = 1046.7$
$T_2 = 461 + 80 = 541$
$\phi_2 = 0.0932$

$$x_2 = \frac{541}{1046.7}\left(0.553 \log_e \frac{1117.2}{867.2} + \frac{821.6}{867.2} + 0.5739 - 0.0932\right)$$

$$= \frac{541}{1046.7}(0.553 \times 0.2546 + 0.947 + 0.5739 - 0.0932)$$

$= 0.5168 \times 1.5685 = 0.812$ = Dryness factor

Available energy $= 778\,[1202.3 + 0.553 \times 250 - (48 + 0.812 \times 1046.7)]$
$= 778 \times 444.3 = 346{,}000$ ft-lb.

[Theoretical water rate per kw-hr. = 2,654,000/346,000 = 7.67 lb.]

GAIN BY THE USE OF HIGH STEAM PRESSURE

9 It has long been recognized that a very large saving in fuel could be obtained by the use of high steam pressure. As early as 1897 DeLaval in Sweden supplied all the power for lighting the Exposition of Arts and Industries in Stockholm with his turbo-generating sets operated from boilers of his own design, using over 1500 lb. pressure. The units used were naturally small, four of them having 100 hp. each and two of them 50 hp. each. Boiler manufacturers in this country are today prepared to build boilers for 350 lb. pressure and see no difficulties in going to 500 lb. or even higher.

TABLE 1 THEORETICAL GAIN DUE TO THE USE OF HIGH STEAM PRESSURE

Absolute pressure, lb.	Corresponding temperature, deg. fahr.	Total heat	Increase in total heat, per cent	Available energy in ft-lb. expanding to 28.5 in. vacuum	Increase of available energy per cent	Net gain in fuel, per cent
200	381.9	1198.5	.....	272,000	.....	.....
300	417.5	1201.9	0.28	293,000	7.72	7.44
400	444.8	1202.5	0.33	304,500	11.96	11.62
500	467.2	1201.7	0.27	312,000	14.7	14.43
600	486.5	1199.8	0.11	319,000	17.2	17.09
700	503.4	1197.4	0.902	323,000	18.7	18.79
800	518.5	1194.4	−0.342	327,000	20.2	20.54
900	532.3	1191.1	−0.617	329,000	20.9	21.51
1000	545.0	1187.6	−0.909	331,000	21.7	22.6

10 The theoretical gain due to the use of high steam pressure is plainly illustrated in Table 1, in which 1 lb. of dry steam at 200 lb. pressure expanded to 28½ in. of vacuum is considered unity. It will be seen that by raising the boiler pressure to only 500 lb. there is a saving in fuel of 14.43 per cent. In money this saving would amount to about $200,000 a year in a plant burning about 900 tons a day with coal costing $5 a ton.

GAIN BY SUPERHEAT

11 The theoretical gain by superheat is shown by Table 2, which is calculated on the basis of an initial pressure of 250 lb. gage expanded to a 29-in. vacuum. It will be seen that this gain is very small, being only 2.9 per cent when superheating up to 300 deg.

12 The practical gain by the use of superheat is often expressed by saying that the water rate is reduced 1 per cent for a certain

number of degrees of superheat. The amount of this decrease varies with turbines of different design, but a figure frequently used is 1 per cent gain in water rate for every 12.5 deg. of superheat. Column 5, Table 2, is based upon this assumption.

13 The actual net gain of fuel in per cent is therefore shown by column 8, which is the difference between column 7 and column 4. It will there be seen that the practical gain by superheat is about two and a half times as great as the theoretical. The reason for this large practical gain is that in a well-designed turbine of, say, the impulse

TABLE 2 THEORETICAL GAIN DUE TO THE USE OF SUPERHEAT

Degrees superheat	Temp., deg. fahr.	Total available energy per lb. of steam	Total B.t.u. per lb.	Per cent increase in coal to produce superheat	Per cent increase available energy due to superheat	Net theoretical gain, per cent	Actual gain, per cent	Actual net gain, per cent
(1)		(2)	(3)	(4)	(5)	(6) = (5-4)	(7)	(8) = (7-4)
0	406	298,000	1202.3	.....	.....	.....	.....	.....
50	456	308,500	1237.0	2.89	3.53	0.64	4	1.11
100	506	318,000	1264.6	5.18	6.72	1.54	8	2.82
150	556	327,500	1290.5	7.333	9.90	2.57	12	4.67
200	606	336,000	1315.6	9.45	12.75	3.30	16	6.55
250	656	341,500	1340.5	11.50	14.60	3.10	20	8.50
300	706	347,000	1365.3	13.55	16.45	2.90	24	10.45

type the magnitude of the total losses is made up in about the following proportions when dry initial steam is used:

	Per cent
Loss due to friction in nozzles and blades and windage loss of disks and blades	20
Leakage loss	3
Rejected energy (due to residual steam velocity)	3
Bearings, packings, etc	1
Total losses	27
Efficiency of turbine	73

14 It will be seen that the first item is by far the most important one, and it is this item which is reduced by the use of superheat. The use of 200 deg. superheat will reduce the friction and windage loss about one quarter or to 15 per cent, and the total loss would then be 22 per cent, making the turbine efficiency 78 per cent. This reduction is effected by the superheat reducing the moisture in all the stages. The reduction is best shown by the entropy-temperature diagram, Fig. 1. From this diagram it will be seen that starting with steam initially dry at 265 lb. absolute pressure and expanding it

adiabatically to 29 in. vacuum through a turbine of 100 per cent efficiency, would result in steam of about 26.5 per cent moisture, whereas if the steam had been superheated to, say, 250 deg., this moisture would be reduced to about 19 per cent, a reduction of almost 30 per cent. In an actual turbine this percentage of moisture is of course a great deal lower, depending upon the efficiency.

15 Table 3 gives approximately the condition of the steam in all the stages of a ten-stage turbine, assuming the turbine has 80 per cent efficiency, is supplied with steam at 250 lb. gage pressure, 250 deg. superheat, and is exhausting into 29 in. vacuum. For com-

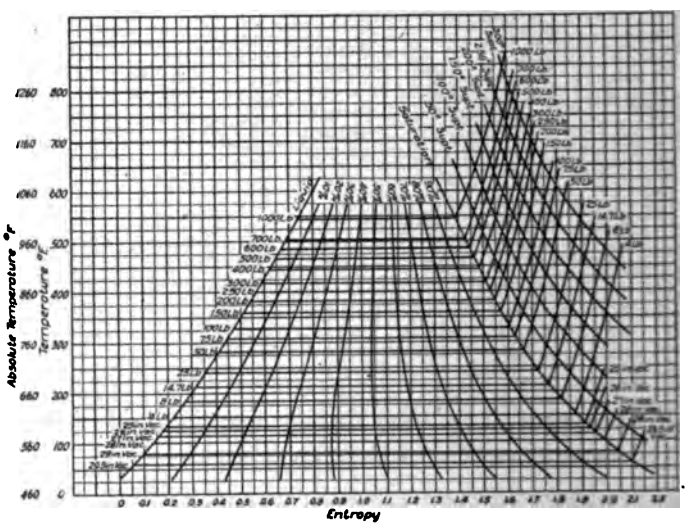


FIG. 1 ENTROPY-TEMPERATURE CURVES

parison the last column of the table gives the steam condition in this turbine had the steam been initially dry.

EFFECT OF MOISTURE ON FRICTION

16 A great many formulæ and curves based upon experimental and theoretical data are given by various authors for calculating the friction losses, and they all have a constant which varies according to the conditions of the steam. Professor Moyer, for example, in his book on steam turbines gives a formula for rotation losses of buckets and wheel disks in which the constant C is as follows:

Superheat, deg.			Per cent moisture		
100	50	0	5	10	20
$C = 0.875$	0.93	1.00	1.08	1.25	2.00

In other words, the friction loss is twice as great with 20 per cent moisture as it is with dry steam.

EFFECT OF THROTTLING

17 Throttling of dry steam always produces superheat; and it has often been said for this reason that there is practically no loss due to throttling, which is true as far as heat is concerned. There is, however, a considerable loss of available energy. The amount of superheat obtained by throttling is easily calculated because the total heat before and after throttling is the same. Assume that

TABLE 3 CONDITION OF STEAM IN THE VARIOUS STAGES OF A TEN-STAGE TURBINE

Assumptions: Steam pressure, 250 lb. gage; superheat, 250 deg.; vacuum at exhaust, 29 in.; turbine efficiency, 80 per cent.

Stages	Steam pressure, lb. per sq. in. abs.	Temperature of steam, deg. fahr.	Superheat, deg.	Per cent moisture	Per cent moisture assuming steam initially dry
Steam chest	265	656	250	.....	.....
1	120	501	160	.....	4.40
2	68	421	120	.....	6.80
3	48	354	75	.....	8.15
4	28	277	30	.....	9.80
5	16	216	.....	0.6	11.50
6	9	188	.....	2.0	13.00
7	4.7	160	.....	4.0	14.50
8	2.4	133	.....	6.5	16.00
9	1.1	107	.....	8.0	17.30
10	0.5	79	.....	10.5	18.70

steam at 200 lb. absolute pressure is throttled down to 100 lb. absolute pressure; then

Total heat of dry steam at 200 lb. abs. = 1198.1
Total heat of dry steam at 100 lb. abs. = 1186.3

Assume that the specific heat of steam is 0.5; then

$$1198.1 = 1186.3 + 0.5 \times t_1, \text{ or } t_1 = 23.6 \text{ deg.}$$

18 The available energy, however, assuming that the steam in both cases is expanded to 28.5 in. vacuum, is:

270,800 ft-lb. with 200 lb. pressure, dry steam
240,200 ft-lb. with 100 lb. pressure, 23.6 deg. superheat,

or a loss in available energy of about 11 per cent.

GAIN BY THE COMBINED USE OF HIGH STEAM PRESSURE AND SUPERHEAT

19 High steam pressure with no superheat has the disadvantage, as will be seen by the entropy diagram, of producing more moisture throughout the turbine, which means more friction. It is therefore advisable to combine high pressure with superheat so as to produce a more efficient turbine.

20 Fig. 2 shows the ratio of available British thermal units in steam to the total heat in the steam, with feedwater at a temperature of 90 deg.

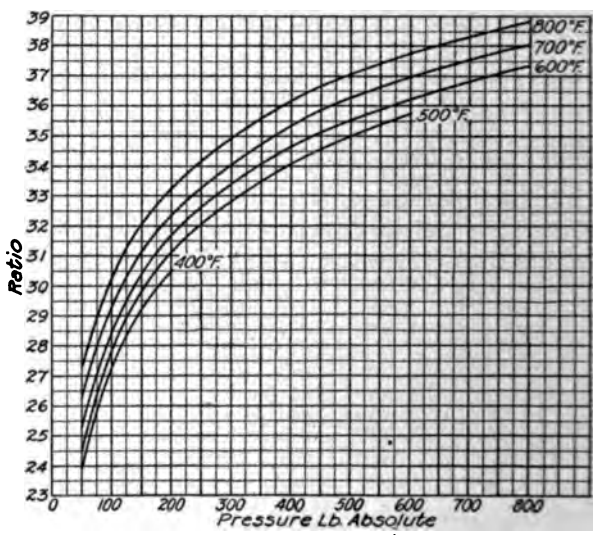


FIG. 2 CURVES SHOWING RATIO OF AVAILABLE B.T.U. IN STEAM TO TOTAL HEAT IN STEAM, FEEDWATER AT 90 DEG. FAHR.

21 The present practice in power plants in this country is to use, with turbine drive, a steam pressure of 200 lb. gage and about 150 deg. superheat (temperature of 538 deg.), with a vacuum of 28.5 in. From Fig. 2 it will be seen that the ratio of maximum available heat for work to the total heat is only about 31.25 per cent.

22 Steam temperatures as high as 700 deg. fahr. are now used in Europe, which with a steam pressure of 500 lb. would give 233 deg. superheat. The ratio of available heat for work would then be about 36.3 per cent, or a fuel saving over the above conditions of 16 per cent.

23 Turbine generator sets are now built having an overall efficiency of over 80 per cent including generator losses, which with a boiler efficiency of 80 per cent would give an efficiency from fuel amounting to $36.3 \times 0.80 \times 0.80 = 23.25$ per cent. One kilowatt-hour = 3412 B.t.u., therefore the B.t.u. required to produce 1 kw-hr. at the switchboard = 3412/0.2325 = 14,600.

24 On the other hand, had 800 lb. pressure and 800 deg. temperature been used, the efficiency would have been 38.75 per cent; and using a turbine efficiency of 85 per cent and a boiler efficiency of 88 per cent (which is obtainable with liquid fuel, forced draft, and preheated combustion air), a kilowatt-hour could be obtained from:

$$38.75 \times 0.88 \times 0.85 = 29 \text{ per cent, or}$$

$$\frac{3412}{0.29} = 11{,}750 \text{ B.t.u., or}$$

$$\frac{11{,}750}{19{,}000} \text{ lb. of fuel oil} = 0.62 \text{ lb.}$$

25 Diesel-engine advocates now claim a consumption of about 0.55 lb. of fuel oil per kw-hr., but with a fuel about 50 per cent higher in price than the grade of fuel which can be satisfactorily burned under a boiler. It will thus be seen that when full advantage has been taken of the various processes that are used in transforming the energy of the fuel into mechanical energy through the medium of steam, the steam process compares quite favorably with results now obtained with internal-combustion engines.

26 The conservation of our fuel resources is a subject which is being very carefully studied by all power-plant engineers at the present time, and improvements along the lines that have been discussed in this paper are now receiving serious consideration.

DISCUSSION

In the discussion following the presentation of the paper a number of questions were propounded which were taken up in order by the author as follows:

Dr. Thurston's remark to the effect that the most efficient all-round superheat would be that which would give dry steam in the exhaust, he said, was correct at the time when moderate steam pressure was used and the efficiency of the prime mover was around 50 per cent. Assuming however, an efficiency in the prime mover of

80 per cent, 200 lb. steam pressure, and an exhaust pressure of 28½ in. of vacuum, in order to obtain dry steam at the exhaust the superheat would be above 1000 deg. or in a territory that was practically unknown at the present time.

When the high-pressure boiler was developed, it would, in his opinion, be smaller, lighter, and cheaper per horsepower than the present boilers.

In regard to the question of moisture, for a given turbine efficiency the moisture was, of course, the same as the theoretical. If in practice the moisture was found to be excessive, it must be caused by the initial condition of the steam: it might have less superheat than assumed, or it might be quite wet when entering the turbine.

In reply to the question whether the first 50 deg. of superheat was not more effective than the last 50 deg. of the 200, he would say that it was, because it reduced the moisture in the high-pressure end of the turbine where the friction loss is greatest. Turbine manufacturers recommended 50 deg. of superheat because it was easily obtained and it at least assured them of dry steam at the throttle. Very few boilers gave dry steam in practice.

In regard to high superheat showing a great saving in fuel with reciprocating engines, it was to be remarked that records of several European vessels operating with steam temperatures around 700 deg. showed that the saving in fuel was in some of them as high as 17 per cent and was sufficient to pay for the cost of installing the apparatus for producing superheat in a few trips across the ocean.

As to an inquiry made regarding the durability of packings, etc., at the higher pressures and temperatures, he would say that in all probability no packing would be used in the piping system and all joints would have to be welded. This, however, should not raise any difficulty. The paper had been primarily intended to point out the direction in which it was necessary for all to work in order to improve fuel economy, and to show that the advantages derived by the use of high steam pressure and superheat were infinitely greater than the disadvantages due to the few practical difficulties which had to be overcome.

No. 1684

NECROLOGY[1]

FREDERICK REMSEN HUTTON

Frederick Remsen Hutton, Honorary Secretary, Past-President, and for twenty-three years Secretary of the Society, died May 14, 1918, at his residence in New York City.

Professor Hutton was born in New York, May 28, 1853. After preparation in a private school in New York, he entered Columbia College, receiving the degree of A.B. in 1873. After graduation he entered the School of Mines, and was given its degree in 1876. A year later he was appointed instructor in mechanical engineering as an associate of the late Prof. W. P. Trowbridge. This was the first recognition which Columbia gave to the important relations of mechanical engineering to other engineering courses. He entered the faculty as adjunct professor in 1881 and became professor in 1890. Upon the death of Professor Trowbridge, in 1892, the chair of engineering which he had occupied was divided, and professorships in civil engineering and electrical engineering were added to the already existing professorships of mining and mechanical engineering. Professor Hutton was made the head of the mechanical engineering department, which he directed until July 1, 1907, when he resigned, and in appreciation of his valued services was elected professor emeritus.

At the time of Professor Hutton's election to the presidency of the Society, an excellent summary of his work at Columbia was prepared by Mr. Fred J. Miller, editor of the *American Machinist*, and published in that journal, from which the following is taken:

> Perhaps his most significant achievement during these years of service has been the development of the great mechanical laboratories of the University, during the period from 1897 to 1900, just subsequent to the transfer of the institution from the downtown site to its present location on Morningside Heights. This equipment includes the Baldwin locomotive mounted upon its testing equipment, the triple-expansion Allis-Reynolds engine, which is a three-stage air compressor, and the hydraulic equipment of the Henry R. Worthington Laboratory. A conservative estimate of the value of this equipment as installed, is not far from $100,000.
>
> It has been the professor's belief that to make experiments in illustration or confirmation of engineering formulas on engines or machines of small size, is to introduce an error not only of degree, but of kind, and that therefore the units should be of sufficient size to guard against this difficulty; and, furthermore, to make research into new fields sufficiently near to the actual conditions of practice so as not to prove actually misleading when their results are applied. The air compressor has been, with him, a favorite form of laboratory apparatus by reason of its illustrating to the student the complete cycle of generated mechanical energy, its storage in compressed air, and the liberation of that energy in a motor having a cycle similar to that of the original steam cylinder.

[1] Those members who died while in military or naval service have asterisks affixed to their names.

In no other educational institution are there any larger units than those which have been hereto gotten together.

The professor is also an earnest exponent of such a method of conducting laboratory instruction as to compel the student to exercise his thinking faculties, not only in devising the experiments and connecting up the apparatus, but in the interpretation of the results. In his discussion of this subject he has referred to the more formal system of definite instruction to the students by the use of printed logs which can be used half automatically as failing to make men out of the raw material. The automatic or log method he has called the "cook-book" system.

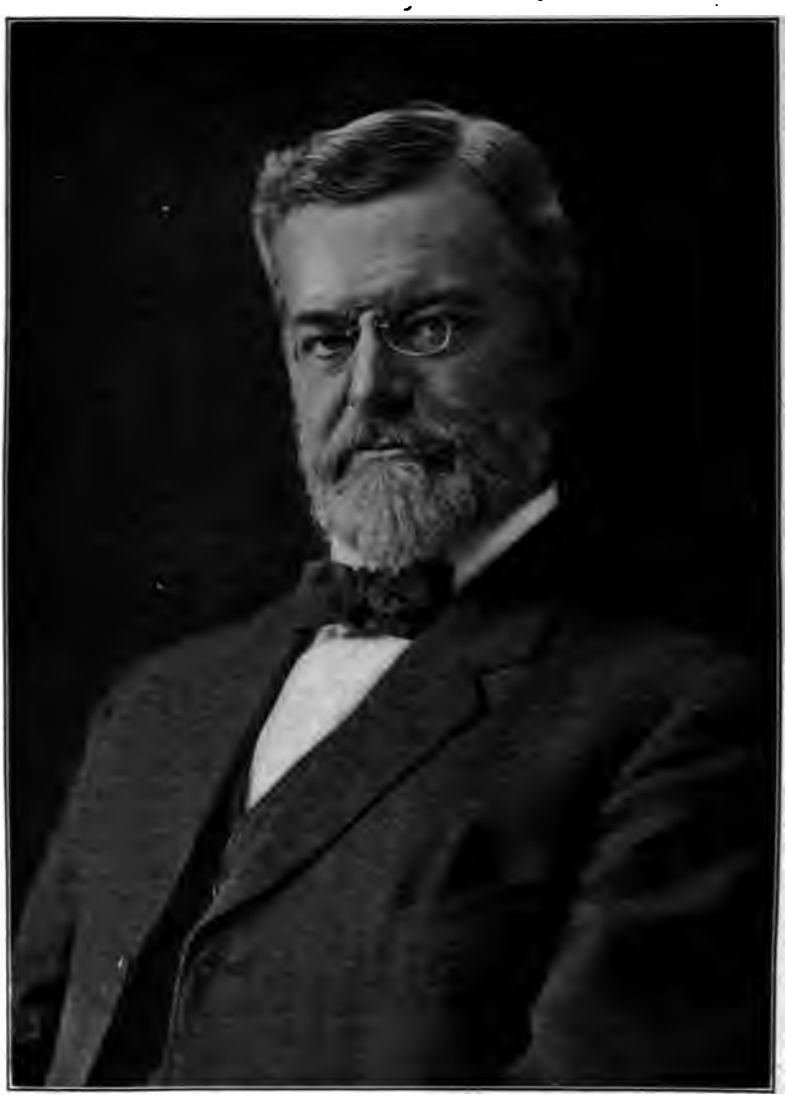
Professor Hutton became Secretary of the Society in 1883, three years after its organization, which was a critical time in its history. The membership was less than 400, and there was great difficulty in meeting expenses from the small sum received for dues, so that initiation fees had been treated as available current income. The previous Secretary, Mr. Rae, had received no salary and the office rent had been provided by reason of his relations with Mr. Henry R. Worthington, one of the founder members.

Professor Hutton was then a young man of thirty, junior professor of mechanical engineering at Columbia University, and able to arrange to give part time to the management of the Society in connection with his duties as a teacher. He was appointed Secretary in March at a salary of $1000 per annum. The Worthington office was given up and for a time the headquarters were in Professor Hutton's study at Columbia University; but it was soon found desirable to have a downtown office, and he rented at his own expense a room in what was known as the Smith Building, at 15 Cortlandt Street, and engaged an assistant whose salary he also paid. Professor Hutton states in his History that: "The location was chosen for its nearness to the ferry and approaches through Cortlandt and Liberty Streets, which were then the downtown entrances to the city from New Jersey and Pennsylvania. The stock of volumes and extra stationery were taken to Columbia University and stored in a dark room available only for such uses. The office furniture of that modest undertaking was a Keuffel and Esser drawing table, some camp chairs and a specially designed stationery holder, somewhat along the lines of the revolving bookcases. There was no typewriter in use for more than a year. Later a bookcase made of pine, with certain locked-up cupboards, was added to receive the periodicals and exchanges."

From that time on, through the wise management and strong personality of the new Secretary, supported by the staunch founder members, who were the backbone of the organization in the early days, the Society grew and prospered consistently year by year, and one by one its many problems and difficulties were overcome. In this regard Professor Hutton displayed the same broad vision of future possibilities that so characterized Professor Thurston, who was the first President. This viewpoint was strongly emphasized by Professor Thurston's presidential addresses, which are recorded in the TRANSACTIONS.

In 1890, the house at 12 West Thirty-first Street was purchased for $60,000. This had been occupied by the Academy of Medicine, and was admirably adapted for a Society; but its acquirement was an ambitious project for a society without funds. The financing was left to a committee, of which J. F. Holloway, Stephen W. Baldwin and Professor Hutton were members.

Bonds were taken up by the membership to the amount of $32,000. A few of the older and wealthier members became guarantors to make good any deficiency should the Society be unable to meet its obligations, but they were never called upon, and the Academy of Medicine took a mortgage of $33,000. Five



FREDERICK REMSEN HUTTON

DIED MAY 14, 1918
SECRETARY OF THE SOCIETY, 1883–1906
PRESIDENT, 1906
HONORARY SECRETARY FROM 1907

thousand dollars of the amount raised was used for alterations and furnishings.

It was at this home where Professor Hutton became so closely identified with the work of the Society and formed so many pleasant associations with the members who came to the meetings or dropped in for a social time. The wisdom of acquiring the property was shown when it was sold in 1906 for $120,000, realizing a profit of nearly $60,000, and providing a fund which was a most helpful factor in procuring property for the new Engineering Societies Building, the gift of Mr. Carnegie.

With regard to the house on Thirty-first Street, Professor Hutton has written:

"It is perhaps difficult at this day and with the present strength, standing and income of the Society to realize what an enormous step and undertaking the purchase and responsibility for that house were to the modest men of that day. If it had failed, the consequences to the Society would have been most disastrous. Its success was the greatest thing that ever happened to it up to that time and for many years."

Professor Hutton's first meeting as Secretary was the Cleveland meeting in 1883, where the papers were for the first time distributed in advance by means of galley proofs, with the cuts printed on separate sheets. From time to time other events occurred which for some special reason were particularly notable. Among these was the trip to Europe in 1889, which had a wide influence in giving international recognition to the Society and establishing the bond of professional fellowship between this and the countries visited. Another was the Chicago Meeting of 1893, at the time of the Engineering Congress held during the Columbian Exposition.

Gradually the Society outgrew its quarters on Thirty-first Street, and after sixteen prosperous years moved to the splendid Engineering Societies Building, which it now occupies jointly with the other engineering societies. Professor Hutton was a member of the Joint Conference and Building Committee appointed to carry out the generous intention of Mr. Andrew Carnegie to provide a necessary building for the use of the several societies and a building for the Engineers' Club, and to plan the proposed structures. He was also Secretary of the Building Committee, and later Secretary of the United Engineering Society. From the fact that the Civil Engineers decided to remain in their own building and the Mining and the Electrical Engineers had no buildings of their own, a great many meetings of the Committee, of which a total of seventy-four were held, besides numberless conferences, took place in the house of the Mechanical Engineers on Thirty-first Street, and during the construction much of the accounting and other business was transacted there.

Professor Hutton was one of the Board of Trustees of the United Engineering Society, which is the holding corporation for the building.

At the end of twenty-three years' service and coincident with the removal to the new building, Professor Hutton resigned his position as Secretary. He felt that the time had come when the Society needed the full time and energies of a Secretary, and should not be compelled to share these with the engineering department of a university. It seemed proper that the retiring secretary, who had led the Society from the modest beginnings where he paid the office rent out of his own pocket up through the successive stages of development, to the point

where it constituted a prime element in a great engineering headquarters for the whole country, should be elected to the presidency. He was made President for the year 1906–1907, and officiated in that capacity for the first time at the Indianapolis Meeting in 1907. At the end of his term he took for his presidential address the subject of the Mechanical Engineer and the Functions of the Engineering Society.

In 1908 he was elected Honorary Secretary, under the constitutional provisions which created such an office, a distinction which he held until his death.

With his varied and complex duties at Columbia University and in the secretary's office of the Society, it was impossible that he should enter largely into literary productions; nevertheless, he was the author of several books and several papers presented to the Society. The earliest of these was an elaborate monograph on Machine Tools for the Census of 1880. At that time technical books were few and engineering periodicals were fewer, and this treatise on machine tools stood out as one of the important documents of the time, and was used by engineering schools for the instruction of their students.

Professor Hutton wrote two textbooks, on Mechanical Engineering of Power Plants and on the Gas Engine. A distinctive and valuable feature of the former was the summarizing of the advantages and disadvantages of the various types and combinations of apparatus used in power plants. He was editor for encyclopedias and dictionaries, notably the Century, of 1911. He was also an occasional contributor to the engineering press on mechanical, automotive and safety engineering subjects as well as on technical education, and a number of his addresses on these and related topics were accorded the wider publicity due them by being reported in the columns of the current technical journals.

Fortunately for the Society, Professor Hutton was prevailed upon to write its history, which was issued by the Society in a handsome illustrated volume in 1915. While the publication is in no sense biographical of any one individual, and refers to Professor Hutton by name in only a few instances, it must nevertheless be regarded as largely a history of his own endeavors and accomplishments, and will long remain a valued and cherished volume to many of his friends and fellow-members. Special attention should be called to the chapter on Some Principles of Society Philosophy, which embodies a remarkably comprehensive statement of the stages of development of a great engineering society and the principles underlying them.

In 1911 Professor Hutton served as consulting engineer to the Department of Water, Gas and Electricity, New York City, and from 1905 to 1911 was vice-chairman of the Museum of Safety. He was consulting engineer to the Automobile Club of America and chairman of its Technical Committee from 1912, in which capacity he supervised the important testing work conducted by the club in its laboratory. He was one of the first engineers to use an automobile and to enter into a study of automobile construction.

Professor Hutton was active in Society affairs in many ways after serving as President, particularly as a member of the Committee on Constitution and By-Laws. In this work he endeavored to meet in a broad and progressive spirit the new conditions which were imposed upon the Society by its growth and expansion into various fields of activity and the establishment of its many Sections. He had, as always, a clear vision of the future and laid his plans accordingly. He was also a member of the John Fritz Medal Board of Award. His interest in young men

was evidenced by his service on the Student Branch Committee of the Society. He often presided at meetings and represented the Society on special occasions, which he always did with a distinction and grace of manner peculiarly his own. Here, as on all occasions, his felicity of expression and ready wit, his cordiality and withal his dignity, were strong characteristics.

In 1882 Columbia conferred upon him the degree of Ph.D. and in 1904 the degree of Sc.D., which is the highest distinction which the University places upon one for scientific and engineering training.

Letters of appreciation of the life and services of Professor Hutton were received by the Society from the following members — all friends of long standing: Wm. H. Wiley, Charles T. Main, Jesse M. Smith, Alex. C. Humphreys, Oberlin Smith, Henry Harrison Suplee, Geo. M. Bond, Worcester R. Warner, Robert W. Hunt, Ira N. Hollis, W. M. McFarland, Ambrose Swasey, W. F. M. Goss, D. S. Jacobus, John R. Freeman, Calvin W. Rice, James Hartness and John A. Brashear. These tributes were published in THE JOURNAL, June 1918, pp. 475–477.

WILLIAM SICKLES ACKERMAN

William S. Ackerman, engineer and architect, died on November 11, 1918, of heart failure, after a brief illness. He was engaged at the time in the service of the Ordnance Department, U. S. A., as supervising engineer of the Government Carbocoal plant being erected at Russell, near Clinchfield, Va.

Mr. Ackerman was born in November, 1868, in Paterson, N. J. He received his technical education at the Stevens Institute of Technology, and was graduated in 1891, with the degree of M.E. His earlier work was in the West, where he acted as Colorado agent for the Ingersoll-Sergeant Drill Co. as draftsman and mechanical engineer for the Standard Smelting and Refining Co. of Durango, Colo., and as assistant superintendent of the Pelican-Dives Mining Company at Silver Plume, Colo. From 1893 to 1897 he was chief engineer of the National Lead Co. He then formed the partnership of Ackerman & Ross, Engineers and Architects, which in 1902, on the retirement of Mr. Ross, became Ackerman & Partridge. The work done by these firms covered nearly every branch of the profession. It included: Carnegie libraries at Washington, D. C., Atlanta, Ga., San Diego, Cal., Port Jervis, N. Y., and Bucknell University, Lewiston, Pa., engineering and chemical laboratories at Stevens Institute, etc., court houses, banks, office buildings, schools and factories in many states. Perhaps the most notable of these from a scientific standpoint was the Morton Memorial Laboratory at Stevens Institute of Technology. Mr. Ackerman made a special study of the requirements of a chemical laboratory and put forward a design containing so many new and admirable features that it has served as a model for many of the more recent laboratories.

On the dissolution of the firm of Ackerman & Partridge in 1905, Mr. Ackerman went into consulting practice in mill construction and power plants and in 1907 became a member of the Passaic Valley Surveys Commission, which he served in the capacity of secretary, until 1913, when he returned to private practice. In 1916 he went with the O'Rourke Engineering Construction Company as expert in patent litigation. While so engaged he offered his services to the Army Ordnance Department, and by a singular coincidence died in service at the plant in Virginia on the day the armistice was declared.

Mr. Ackerman was a member of the New Jersey chapter of the American Institute of Architects, and the Alumni Association of the Stevens Institute of Technology, of which he was president in 1902. He was a former member of the American Institute of Mining Engineers. He became a member of the Society in 1891.

WALTER ANTOSCH *

Walter Antosch was born in New York City on March 17, 1896. He attended the city schools and later Stevens Institute of Technology, from which he was graduated in 1917 with the degree of M.E. For about six months after his graduation he was connected with the Standard Aircraft Corporation, Elizabeth, N. J., serving first in the drafting room, then in the engineering department and finally as assistant superintendent in the production department, where he had charge of routing material through the shops. He resigned his position at the end of that time and enlisted in the United States Naval Reserve Force and was assigned to the Naval Engineering School, where in a very short time he won the rating of machinist. He was then assigned to the U. S. S. *Westbridge*, which was torpedoed on August 15, 1918, when he was instantly killed. He was buried on August 28 in the Kerfautras Military Cemetery, Brest, France.

Mr. Antosch also served in the recent Mexican border trouble and was at that time connected with the First Field Hospital of the New York National Guard. He became a junior member of the Society in 1918.

EDWARD R. ARCHER

Edward R. Archer was born on March 9, 1834, at Old Point Comfort, Va. He received his early education in the private schools of Hampton and Richmond, Va., and at the age of 17 entered the employ of the Tredegar Iron Works of the latter city, where he served an apprenticeship of four years in the shops and drafting room of that company. On June 26, 1856, he was appointed third assistant engineer in the U. S. Navy and served in that capacity on the U. S. Frigates *Roanoke* and *Powhatan*, making a two and a half year's cruise around the world. At the close of the cruise he returned again to the Tredegar Iron Works and remained in their employ until the outbreak of the Civil War, when he entered the service of the Confederate Navy. When peace was declared he again reëntered the employ of the Tredegar Iron Works, and at the time of his death was chief engineer of the company.

In addition to being a member of the Society since 1890, Mr. Archer was one of the founders of the Virginia Mechanics Institute. He died at his residence in Richmond on March 13, 1918.

EDWARD CARRINGTON BATES

Edward C. Bates was born in Boston, Mass., in 1848. He was educated in the private schools of that city, preparatory to attending Brattleboro Academy, after which he went to the Massachusetts Institute of Technology where he was graduated with the first class sent forth, that of 1868.

* Those members who died while in military or naval service are indicated by asterisks affixed to their names.

He then began work in his chosen profession as civil and railroad engineer and on going West was active in the earliest days of the Union Pacific Railway. During his career he held the position of superintendent of works of the Union Electric Sign Signal Co., Boston, and the same later with the Union Switch & Signal Co., Pittsburgh. He was for five years superintendent with the Hall Typewriter Co. and for eleven years railroad representative for the Crosby Steam Gauge & Valve Co., Boston. He was also associated for a period with the Ewald Iron Co., St. Louis.

Mr. Bates was an inventor of note and his later years were devoted to inventing, although in a less active way than formerly. He became a member of the Society in 1899. He died very suddenly on July 23, 1918.

HENRY ARTHUR BAYFIELD

Henry A. Bayfield was born in Charlottetown, Prince Edward Island, Canada, on June 19, 1873. He was graduated from McGill University, Montreal, in 1896, with the degree of Bachelor of Applied Science, having taken the mechanical engineering course.

The first two years after his graduation he spent at the shops of the Intercolonial Railway, Moncton, N. B., as machinist and junior mechanical draftsman, and in testing locomotives on the road. He was also a year in the Great Northern Railway shops at St. Paul, Minn., where he was draftsman in charge of the office; later he was made superintendent of the company's shops at West Superior, Wis. For a short period he was with the Dardanelles Mining Company, Sandon, B. C., overhauling and operating their plant. From 1899 to 1900 he was connected with the Albion Iron Works and Victoria Machinery Depot, Victoria, B. C., as a designer of small marine engines, boilers, etc., leaving this firm to become senior designer on dredging and hoisting machinery, air compressors, shop appliances, etc., with the James Cooper Mfg. Co., Montreal. In 1901 Mr. Bayfield was appointed mechanical superintendent in charge of dredging fleet, shops and shipyard for the Harbor Commissioners of Montreal. About three years later he entered on private practice in Vancouver, B. C., and with the exception of an interval with the British Columbia General Contract Company, continued in private practice until 1909, when he entered the service of the Department of Public Works of Canada, being appointed superintendent of dredging for British Columbia. In December 1912 Mr. Bayfield was made chief engineer in charge of all estimating and designing of the Vancouver Machinery Depot Company, where he remained until 1913, when he was again called upon by the Dominion Government to design a self-propelling hydraulic dredge. In 1914 he returned to private practice at Vancouver, B. C., engaging principally in consulting work in connection with dredging and marine matters, but was called in 1915 to the Department of Railways and Canals of Canada to take the position of mechanical engineer in charge of all mechanical and marine work at Port Nelson, Manitoba. Late in the same year Mr. Bayfield became chief engineer with Norton, Griffiths & Co., Ltd., St. John, N. B., in connection with the harbor-improvement contract. In 1916 he was called on by the British Ministry of Munitions of War to take charge of the Enfield rifle production at the Winchester Repeating Arms Company, New Haven, Conn., where he remained until the summer of 1917, when he was appointed engineer in charge of the Ogden Point assembly plant of the Imperial

Munitions Board, Victoria, B. C. He held this position at the time of his death, February 12, 1918.

Mr. Bayfield was a member of the Institution of Mechanical Engineers (Great Britain) and an associate member of the Canadian Society of Civil Engineers. He became a member of the Society in 1913.

PATRICK JOSEPH BEAKEY

Patrick J. Beakey was born in Glann, Ennistymon, County Clare, Ireland, on July 16, 1881, and was educated there in the Christian Brothers' School.

He came to the United States in 1900 and worked as a machinist for the P. & F. Corbin Co., New Britain, Conn., and for the Pratt & Whitney Co., Hartford, Conn. He was employed in 1903 by the Underwood Typewriter Co., also in Hartford, to build special machinery. In 1908 he joined the tool-making force of the Royal Typewriter Co. and was in a short time promoted to the foremanship of the type department. In this position he assisted in the development and production of typemaking machinery and tools, and designed and produced several styles of typewriter type. At the time of his death Mr. Beakey was holding this position.

Mr. Beakey died on October 24, 1918, of Spanish influenza. He became an associate-member of the Society in 1915.

A. C. BEESON

A. C. Beeson was born in Salem, Ohio, on February 26, 1845. He was educated in the "village schoolhouse" there, obtaining in addition a fair knowledge of mechanics in his father's machine shop. His first employment was at Pithole, Pa., in 1865, where he engaged successively in pumping and drilling wells. It was not until 1868 that the opportunity, which proved to lead to his life's work, came to him when he was engaged as gager by the Titusville Pipe Co. and assigned to duty in the Pleasantville district. In June 1870 he entered the service of Vandergrift & Forman and constructed a pipe line from White Oak Station, now Trunkeyville, to Fagundas. The rapid extension of the oil fields in the early seventies was accompanied by unusual activity in pipe-line construction and Mr. Beeson was called on to construct pipe lines in districts of widely separated localities.

When Vandergrift & Forman organized the Fairview Pipe Line, the piping system was vastly extended under Mr. Beeson's direct supervision. He remained with this company and its successor, the United Pipe Lines, until 1885, when he purchased and took charge of a natural-gas plant in the lower-country oil towns. In 1889 he disposed of his gas interests and returned to the pipe-line industry as superintendent of the Western & Atlantic Pipe Line, with headquarters in Pittsburgh. He was appointed superintendent of the Indiana Pipe Line upon its organization in 1899 and later vice-president, which position he held at the time he was taken ill. He died on September 10, 1918. He became an associate-member of the Society in 1914.

ARTHUR HENRY BERGES *

Arthur H. Berges was born on July 28, 1886, in Burlington, Iowa, and was educated in the schools of that city, later attending Purdue University, from

which he was graduated in 1910 with the degree of M.E. His first employment was with the Chicago & Northwestern Railway Co., Chicago, Ill., as special apprentice. In the early part of 1911 he became connected with the International Harvester Co., and had charge of the production in the tractor works, Chicago. His next position was with the H. W. Schott Co., engineers in Chicago, where his duties gave him charge of construction on the power house of a hydroelectric development at Ballville, Ohio. For a short period in 1913 he worked in the mechanical department of Sargent & Lundy, an engineering firm in Chicago, leaving to become draftsman in the shop-engineering department of the Chicago & Western Indiana Railroad Co. At the outbreak of the war he was employed as mechanical draftsman in the Rock Island Arsenal, Ill. He resigned from this position to enlist in the 23rd U. S. Engineers. He was killed in action in France on September 13, 1918.

Sergeant Berges became a junior member of the Society in 1914.

LAWRENCE HOWARD BERTSCH *

Lawrence H. Bertsch, Captain in the Engineering Division of the Ordnance Department, U. S. Army, died at the Walter Reld Hospital, Washington, D. C., on October 13, 1918, after a four-days' illness of influenza followed by pneumonia.

Captain Bertsch was born in Cambridge City, Ind., on October 18, 1879. He attended Earlham College, Richmond, Ind., from 1898 to 1901. In 1902 he received his A.B. degree from Indiana University and the following year entered the University of Michigan, from which he was graduated with the degree of M.E. in 1907. From then until his enlistment in June 1918 in the U. S. Army he was associated with Bertsch & Co., Cambridge City, Ind., manufacturers of shears, punches, rolls and presses. He served in various capacities in office and plant, including those of sales manager, superintendent, general manager, chief engineer and finally as vice-president of the company.

He became a member of the Society in 1918. He was also a member of the Engineering Society of Indiana.

ALFRED BETTS

Alfred Betts was born on October 1, 1835, in Wilmington, Del., and was educated at the Friends' School there. He served his apprenticeship with the firm of Pusey, Jones & Betts, Wilmington, afterward becoming a member of the firm. He was a partner in the firm of E. & A. Betts, manufacturers of machine tools, and later became president of the Betts Machine Co., until his retirement in 1889. He was a member of the Board of Water Commissioners of Wilmington for six years.

Mr. Betts died on December 1, 1918. He became a member of the Society in 1881.

ALBERT BLAUVELT

Albert Blauvelt was born in Philadelphia, Pa., on June 7, 1862. After graduation from the Kingston Academy, Kingston, N. Y., he served an apprenticeship in the drafting room of F. L. Roberts, New York. From 1879 to 1883 he was connected with the McEntee Locomotive Works, Rondout, N. Y., and

with the West Point Foundry. The following year he was in the employ of the Lidgerwood Co., Brooklyn, N. Y. He was next associated as designer and expert draftman with the Fall Steam Pump Co., the Cold Springs, N. Y., Rifle Works, and the Baldwin Locomotive Works, respectively. From 1890 to 1894 he was with the Edison Electric Co., Orange, N. J., and then with the American Oil Co. as engineer in the insurance department. In 1894 he entered the employ of the Western Factory Insurance Association, Chicago, Ill., and at the time of his death, January 4, 1918, held the position of associate manager.

Mr. Blauvelt was among the pioneers to bring into prominence the profession of fire-protection engineering and in that profession he was recognized as an authority. He became a member of the Society in 1896.

W. A. BLONCK

W. A. Blonck was born on April 30, 1872, in Wriezen, Germany. His early education he obtained in the Real Gymnasium of Wriezen, later receiving the degrees of M.E. and E.E. from Mittweida, Saxony, in 1893.

His first position was with the Royal Saxon Railways, Dresden, on construction work of transmission lines in connection with a three-phase power station for Dresden depots. In 1894 he was employed by Körting Brothers, Hanover, Germany, to design electric machinery and apparatus, and the following year he was connected with Siemens and Halske, of Magdeburg, Germany, as estimator and supervisor of construction of isolated factory plants. From 1896 to 1901 he was with Ganz & Co., Budapest, Austria-Hungary, working on estimates and supervision of construction of steam and hydraulic municipal plants in Bulgaria, Hungary and Austria. In 1901 he came to the United States and for about a year was with the Chicago Edison Co., Chicago, Ill., on the preliminary work of the design of the large Fisk Street power plant. From 1902 to 1904 he was associated with the Arnold Electric Power Station Co., Chicago, when he became electrical engineer in charge of construction and operation for the Chicago & Milwaukee Electric Railroad Co. The years from 1905 to 1912 he had consulting offices in Chicago where he specialized on reports, design and construction of railway, light and industrial plants. In 1912 he became president of the W. A. Blonck Co., Inc., Chicago, which position he occupied at the time of his death, January 14, 1918.

Mr. Blonck was particularly interested in the development of the boiler efficiency meter and upon his submitting his investigations and tests in that connection to The Franklin Institute, received a Certificate of Merit for establishing graphically the zero method of best boiler efficiency. He also conducted special investigations of boiler-furnace operation and definite methods of doing away with guesswork in the fire room. He became a member of the Society in 1916.

GEORGE URQUHART BORDE

George U. Borde was born in January, 1871, in New Orleans, La. He received his B.A. degree from Tulane University in 1888 and his M.A. in 1890. He served an apprenticeship in the Schenectady, N. Y., works of the General Electric Co., where he was assigned to the testing room of the armature department tube works.

From 1890 to 1893 he was district engineer of the southern district for the Edison General Electric Co., designing and supervising the light or street railway plants of Charlotte and Raleigh, N. C., Atlanta and Savannah, Ga., Chattanooga, Nashville and Memphis, Tenn., and of a number of other southern cities. From 1893 to 1896 he was connected with contracting work in Memphis. Later he opened consulting offices in New Orleans, La., where he completed engineering work in connection with the new Hotel Denechaud, and the Great Southern Co.'s Light and power installation at Bogalusa, La.

Mr. Borde, at the time of his death, December 17, 1918, was by all odds one of the most prominent consulting engineers in the city of New Orleans. He was retained by the Great Southern Lumber Co. and also by the United States Industrial Alcohol Co. In connection with his work for the latter, his investigations in regard to the process of manufacture of ethyl alcohol from wood waste was probably his most important work. He also did a large amount of industrial and other appraisal work throughout the southern states. He was one of the oldest members of the New Orleans Section of the Society, having become a member in 1909.

AUGUST H. BORNHORST *

Lieut. August H. Bornhorst was born on August 1, 1888, in St. Mary's, Ohio. He received his early education in the schools of St. Mary's and then attended Ohio State University, from which he was graduated in 1911 with the degree of M.E.

He first worked with the Ford Motor Co., Detroit, Mich., as machine designer on a 5000-hp. gas engine. In March 1912 he was assigned through a civil-service appointment to the U. S. Engineer's Office, Seattle, Wash., as mechanical draftsman, where he designed cranes for handling concrete work and designed and laid out lock gates, lock-gate machinery and a proposed emergency dam. In March 1916 he became connected with the Puget Sound Navy Yard, Bremerton, Wash., as a marine-boiler and engine draftsman. Later he was connected for a short period with the Seattle Machine Works.

In July 1917 he entered the service as a first lieutenant in the Signal Officers' Reserve Corps and was afterward transferred to the Aircraft Production, Air Service Branch of the Army, in which he was serving at the time of his death, December 7, 1918.

Lieutenant Bornhorst became a junior member of the Society in 1916.

EMIL BREZINSKY

Emil Brezinsky was born in New York City on March 4, 1867. He was educated in the public schools of Minneapolis and attended the University of Minnesota. He served his apprenticeship with the Wilford Mfg. Co., Minneapolis. From 1898 to 1907 he was connected with the Allis-Chalmers Co., Milwaukee, as draftsman, and later as chief draftsman on mill construction, power-plant work and in designing and superintending of construction work. He was next associated with the Minneapolis Steel & Machinery Co. in the engine and mechanical department as chief draftsman and assistant engineer; he also designed and developed gas and steam engines, and from 1910 to 1912 was acting chief engineer of the company.

Mr. Brezinsky spent a number of years in Russia representing the Allis-Chalmers Co., and later the International Engineering and Trading Co. At the time of his death in February 1918 he was connected with the Strong-Scott Mfg. Co., Minneapolis.

Mr. Brezinsky became a member of the Society in 1912.

GAIL H. BROWNE

Gail H. Browne was born on March 12, 1871, in Salem, N. Y. He was educated in the public and high schools of Chicago, attending also the Chicago Medical College. He also spent two years in the Dental and Medical College of Northwestern University.

He spent the first five years after leaving college as surveyor and draftsman with the Chicago & North Western Railway and then with the International Harvester Co., and Swift & Co., at Chicago. In 1897 he became U. S. inspector of pier work and dredging in the Grand Rapids district. After one year in this district he became engineer in charge of the civil engineering department, McCormick division of the International Harvester Co. In 1905 he was employed by Ford, Bacon & Davis, engineers, New York. Since that time he has been actively engaged by this firm on important design and construction work, principally at Chicago, Memphis, New Orleans, Allentown, Pa. and in the New York office.

Mr. Browne died at his home in Glen Ridge, N. J., on December 7, 1918. He was a member of the Louisiana Engineering Society. He became a member of the Society in 1916.

CHARLES MUNROE BURGESS

Charles M. Burgess was born in 1843 in Michigan. He served his apprenticeship with his father, a manufacturer of machinery in Windsor Locks, Conn. For about seven years he worked in the U. S. Armory at Springfield, Mass., and with the Collins Co., Collinsville, Conn., obtaining valuable shop experience. In 1866 he became associated with the Aetna Cutlery Works, New Britain, Conn., and about a year later entered the employ of Russell & Erwin as tool maker and was promoted shortly to foreman of the machine shops and in 1879 to the position of superintendent. In 1898 he retired from active business life.

Mr. Burgess was a member of Company C, 25th Regiment, Connecticut Volunteer Infantry, during the Civil War. He died on September 27, 1918. He became a life member of the Society in 1897.

WILLIAM BURNHAM

William Burnham was born in Philadelphia on March 20, 1846. He was educated in private schools in Philadelphia and Allentown, Pa., and at the Lawrence Scientific School, Cambridge, Mass. After spending some years in the employ of the Baldwin Locomotive Works, in 1871 he became assignee for William Butcher, who first manufactured steel locomotive tires in the United States. When the business was reorganized as the Standard Steel Works, he was made secretary and treasurer, subsequently becoming chairman of the board. He was also a director of the Baldwin Locomotive Works.

Mr. Burnham was a member of a number of clubs. He was president of the Pennsylvania Working Home for Blind Men. He became an associate of the Society in 1888. He died on February 25, 1918.

GEORGE GOODWIN CALDWELL

George G. Caldwell was born on June 22, 1857, in Peoria, Ill. He was educated in the public schools of Michigan and at Olivet College, Olivet, Mich. He served an apprenticeship as machinist with the Benjamin & Fischer Co., Chicago, Ill., from 1878 to 1880 and then worked for the next five years in various shops in Massachusetts and Rhode Island, gaining general experience in the construction of steam engines and boilers. About 1890 he became engineer for the Calumet Electric Street Railway Co., Chicago, and installed its plant. Subsequently he went into business for himself as construction engineer. From 1907 to 1909 he was connected with the Wheeler Condenser & Engineering Co., Chicago, erecting and operating machinery. In July 1910 he entered the employ of H. M. Byllesby & Co. as construction superintendent on installations covering buildings and general power-plant machinery, and remained in that capacity except for a short interim until his death, on July 27, 1918. While in this position he had complete charge of the installation of important works for the Oklahoma Gas & Electric Co.; Oklahoma City, Okla.; the Northern State Power Co., Minot, N. D.; the Union Light, Heat & Power Co., Fargo, N. D.; the Interstate Light & Power Co., Galena, Ill., and the Ottumwa Railway & Light Co., Ottumwa, Ia.

Mr. Caldwell became an associate-member of the Society in 1916.

CHARLES C. CHRISTENSEN

Charles C. Christensen was born on September 30, 1851, in Copenhagen, Denmark. He attended the technical college at the Navy Yard, Horten, Norway, where he studied marine and mechanical engineering. He served an apprenticeship in shop practice and drafting from 1871 to 1875 in Norway. The next four years he worked with the firm of Jansen & Dahl, Norway, as a designer on iron vessels and on engines.

In 1880 Mr. Christensen came to the United States, where he was employed by the Allis-Chalmers Co. as draftsman. From 1882 to 1888 his position was that of designer of mining machinery and at the end of that period he was placed in charge of the engineering and drafting department. From 1889 until the time of his death, December 13, 1918, he held the position of estimating engineer.

Mr. Christensen was the author of a number of articles relating to mining machinery which have been published in both American and English mining journals and also translated for Spanish and German technical periodicals. He became a member of the Society in 1890.

HOWARD L. COBURN

Howard L. Coburn was born in Patten, Me., in 1867. He was graduated in 1887 from the Massachusetts Institute of Technology and up to the time of his death had been associated in its development.

Mr. Coburn designed some of the largest cotton mills and power plants in New England and until 1904 devoted himself to that phase of his profession. About that time he became associated with the Ambursen Construction Co., New York, as chief engineer and director, and in that capacity began the building of dams.

One of the most important of his works was the construction of the Guayabal Dam for the United States Irrigation Service in Porto Rico. He also put the Bassan Dam across the Bow River in Alberta for the Canadian Pacific Railway, and the Jordan River Dam on Vancouver Island, B. C. In this country he built the Shoshone and Laprelle Dams in Wyoming, the dam at Akron, Ohio, and the Pittsfield Dam, located at Pittsfield, Mass.

In addition to this work he was associated as consulting engineer with Henry L. Doherty & Co., E. W. Clarke & Co. and H. M. Byllesby & Co.

Mr. Coburn was a member of the American Society of Civil Engineers, the Engineers' Clubs of New York and Boston and of the Technology Club. He became a member of the Society in 1901. He died on June 19, 1918.

LESTER WARREN COGSWELL

Lester W. Cogswell was born in January, 1880, at Charlestown, Mass. He was educated in the public schools of that city and was graduated from the Mechanics' High School.

In 1898 Mr. Cogswell obtained employment in the engineering department of the B. F. Sturtevant Co., Jamaica Plain, Mass., where he served a two-year apprenticeship. Later he was associated with the following firms: the Mason Regulator Co., Dorchester; the Blake Pump Works, East Cambridge; the United Shoe Machinery Co.; the Sub-Target Gun Co.; The Walworth Manufacturing Co.; the Globe Ore Reduction Co., and the United Printing Machine Co., all in Boston.

In the latter part of 1916, Mr. Cogswell became connected with the Kinney Manufacturing Co., also in Boston, where he held the position of designer of engines and rotary pumps. He was with this concern at the time of his death, September 29, 1918.

Mr. Cogswell became an associate-member of the Society in 1917.

MURRAY COPES CONLEY

Murray C. Conley was born on December 30, 1889, in Lamar, Mo., and was educated in the public schools of Wichita, Kan. He was graduated from the University of Kansas in 1909 and the following year took a post-graduate course in efficiency engineering.

His first position was with the Dewey Port Cement Co., Dewey, Okla., where he installed the cost system, assisted in laying out and had charge of the construction of a pulverized-coal mill of 100 tons capacity. In September 1913 he became connected with the McEwen Manufacturing Co., Tulsa, Okla., where he assisted in the installation of the Taylor system of scientific management, later having charge of the design and testing on an experimental series of reversing gas engines. His next position was with the Carter Oil Co., Tulsa, where he was employed in laying out walls for tank forms. In October 1915 he became associated with the Pitcher Lead Co., Joplin, Mo., where he super-

vised the reconstruction of one of their small lead smelters and the construction of a new lead smelter at Galena, Kan. Later he had charge of the construction of a large zinc-ore smelter at Henryetta, Okla. In June 1916 he took a position with the Henry L. Doherty Co., New York City, where he was employed in developing the process of pumping crude oils from the Kansas wells. Later he was assigned to one of the subsidiary companies, the Lorain County Electric Co. and was construction engineer on a large electric power plant at Lorain, Ohio, which position he held at the time of his death, December 21, 1918.

Mr. Conley became an associate-member of the Society in 1917.

HARRY H. COOK

Harry H. Cook was born on October 31, 1885, in Jamaica Plain, Mass., and received his early education in the grammar schools of that city, later attending the Mechanic Arts High School, Boston. From there he went to the Massachusetts Institute of Technology, from which he was graduated in 1906 with the degree of B.S.

He was first employed by the Coffin Valve Manufacturing Co., Neponset, Mass., as chief draftsman; later he was advanced to the position of chief engineer of the company. In 1911 he became associated with the Providence Engineering Works, Providence, R. I., as sales engineer, resigning to become engineer with the Chapman Valve Manufacturing Co., Indian Orchard, Mass. In 1917 he was made chief engineer for the company, which position he was holding at the time of his death, December 15, 1918.

Mr. Cook was affiliated with a number of fraternal associations. He became a junior member of the Society in 1910 and was promoted to full membership in 1918.

STANLEY SHIELDS COOKE *

Stanley S. Cooke was born on August 9, 1893, in Denver, Colo., and was educated in the public schools there. He attended the University of Colorado and was graduated in 1915 with the degrees of B.S. and M.E. Upon graduation he was connected for short periods with the following firms: the American District Steam Co., Tonawanda, N. Y., on steam-heating main installations; the Denver Gas & Electric Light Co., Denver, Colo., in the transformer department, repairing irons and fans and testing transformers; the Union Pacific Railroad Co., as special apprentice in the motive-power and construction department. He worked for about a year for the Union Metallic Cartridge Co., Bridgeport, Conn., and then took a position with the Lake Torpedo Boat Co., in the same city, on the construction of submarines.

Three weeks after our declaration of war he enlisted in the Navy Coast Guard Service and was sent to Fort Trumbull, New London, Conn., for training and afterwards assigned to the cutter *Tampa*, which left in October to engage in patrol and escort duty in European waters. In June 1918 Mr. Cooke was made first gunner and in August appointed coxswain, and the following month received orders directing his transfer to the Naval Academy to attend the Officers' Training School. On the night of September 26, however, while the *Tampa* was in the British Channel doing escort duty with the fleet, a violent concussion was felt but the cause was not then ascertained. Upon reaching

port it was discovered that the *Tampa* was missing. Destroyers immediately set out to hunt for the vessel but apart from a little wreckage, some life preservers marked *Tampa* and two bodies in uniform, nothing else was discovered. The *Tampa* during her year's service abroad had made eighteen trips between Gibraltar and English ports and may be said to have rendered a real service to the Allied cause. He became a junior member of the Society in 1916.

PAUL HENRY CORDES *

Lieut. Paul H. Cordes, who was killed in action on the western front in France on September 12, 1918, was born in Altona-Hanover, Germany, on February 17, 1887. He came to this country when he was about eleven years old and was educated in the public schools, later attending evening school, where he took the technical course.

In 1906 he became associated with the Henry R. Worthington Co., Harrison, N. J., works of the Worthington Pump & Machinery Corporation, where he was assistant to the superintendent of the erecting department. His duties there gave him charge of the erecting and testing work on steam and centrifugal pumps, surface condensers, etc. He also assisted in the supervision of the outside construction work. In 1913 he was transferred to the Chicago office as engineering salesman, assisting and having charge of the testing works on large triple-expansion pumping engines, centrifugal pumps and condensers, as well as making experimental and research tests of such machinery, which position he was holding at the time of his enlistment, May 1917. He held the rank of First Lieutenant in Company C, 30th Engineers, Gas and Flame Division.

Lieutenant Cordes became an associate-member of the Society in 1916.

WILLIAM THOMAS COYLE

William T. Coyle, of the engineering department of the U. S. Naval Experimental Station, New London, Conn., died on December 18, 1918, of pneumonia.

Mr. Coyle was born in Hartford on January 11, 1887, and was educated in the public and high schools of that city. In 1905 he started work for the Sterling Blower Co., Hartford, as detailer, designer and draftsman on heating, ventilating and dust-carrying systems. From 1907 to 1909 he was connected with the Pope Manufacturing Co., Hartford, as draftsman. His next position was with the Dwight Slate Machine Co., also located in Hartford, as a designer of drill presses, gear cutters, marking machines, etc. In 1910 he became connected with the Bullard Machine Tool Co., Bridgeport, as a designer of boring mills, roughing lathes, etc.

After four years with this company he became special engineer for the Putnam Machine Co., Fitchburg, Mass., where his work dealt with the development of a new line of boring mills. From 1915 to 1917 he was with the Winchester Repeating Arms Co., New Haven, as designer of equipment and assistant chief draftsman, when he again returned to the Putnam Machine Co., until October 1917. At that time he became associated with the Deane Machine Co., Fitchburg, as secretary and mechanical engineer. In the summer of 1918 he was called to the Naval Experimental Station.

Mr. Coyle became an associate-member of the Society in 1918.

JOHN HORTON DALLY

John Horton Dally was born on July 10, 1868, in Lafayette, N. J. He was educated in the public schools of Newark, N. J., later attending the Newark High School and the Newark Technical School, of which he was a graduate. After serving a three years' apprenticeship with the Watts-Campbell Co. of Newark, N. J., he entered the shops of the concern where he remained from 1891 to 1895. During the time he was with the Watts-Campbell Co. he spent about six months in the City of Mexico installing the first electric lighting plant. He was one year with the Richmond Locomotive Works and also the Whitehall Engineering Company. He was also connected for short periods with the Colorado Automatic Refrigerating Company and with the New York Refrigerating & Construction Company. He was chief engineer of the Waldorf-Astoria Hotel, New York, for about a year and a half, and from 1896 to 1902 was chief engineer of the Carnegie Music Hall, New York.

At the time of the construction of the present building of the New York Stock Exchange in 1902, Mr. Dally entered the employ of the Exchange as chief engineer and took an active part in the mechanical improvements introduced during the erection of the building and in the many changes and improvements made since, among these being the pneumatic-tube system now in use on the floor of the Exchange, which was installed in 1917 under his supervision.

Mr. Dally also acted as supervising engineer for the Fine Arts Society since 1897 and as consulting engineer for the New York Quotation Company.

Mr. Dally became a member of the Society in 1903. He died on December 23, 1918.

GEORGE WILLIAM DICKIE[1]

George W. Dickie, a Manager of the Society from 1895 to 1898 and a member since 1892, and known to the general public as the "Builder of the Oregon," died on August 17, 1918, while actively engaged in the service of the United States as Chief Inspector at the Moore & Scott Shipbuilding Yards, Oakland, Cal.

Mr. Dickie was born in Arbroath, Scotland, on July 17, 1884. He came to the United States with his parents in 1869 and in the same year reached San Francisco. Very soon after his arrival he was employed to erect a gas plant at North Beach. This work successfully completed, he then became connected with the Risdon Iron Works where his work took a wide range. He designed the first successful triple-expansion engine ever built in the United States, and within a few years had made himself famous by designing the first Scotch marine boiler on the Pacific Coast and also the first successful compound steam engine. Several of the latter are still in operation, notably those on the old steamers *Santa Cruz* and *Gypsy*. On one occasion he secured for his firm a large contract for mining machinery, making a proposition which was accepted as against another proposal by Mr. Irving M. Scott, of the Union Iron Works. This kind of successful competition was not to Mr. Scott's liking and resulted in his making an offer to Mr. Dickie, which was accepted. He thus became a member of the staff of a concern in which he had ample opportunity to apply his constructive genius. He was manager of the Union Iron Works from 1883 to 1905, and during that

[1] A tribute to the character and professional attainments of Mr. Dickie by a friend of 30 years' standing, Mr. C. E. Grunsky, Mem. Am.Soc.C.E., appeared in THE JOURNAL October 1918.

period designed many privately owned ships, in addition to the following vessels for the Government: Battleships, *Oregon*, *Wisconsin* and *Ohio;* the cruiser *Olympia*, later the flagship of Admiral Dewey; the cruisers *South Dakota*, *San Diego*, *Charleston* and *Milwaukee*, the gunboat *Wheeling*, and destroyers, *Paul Jones* and *Perry*.

Mr. Dickie wrote many papers bearing upon marine architecture and engineering, and also on matters relating to the American merchant marine. He was recognized as an authority on such matters and was widely quoted. Immediately on the outbreak of the war he offered his services to the U. S. Government, and was appointed chief inspector for the Government at the Moore and Scott Shipbuilding Works as already stated. He also gave much attention to the devising of means for protecting the Allied shipping against attacks by submarines.

Mr. Dickie was a life member of the Technical Society of the Pacific Coast, and also a member of the California Academy of Sciences and the American Society of Naval Engineers.

ROBERT MUNN DIXON[1]

Robert M. Dixon, for 34 years a member of The American Society of Mechanical Engineers and the chairman of its Finance Committee, died suddenly at his home at East Orange, N. J., on October 17, 1918. His death came as a great shock to his many friends, as he had been at business regularly and apparently had been in his accustomed health and had attended to his affairs with his usual energy and attention to their many details up to the very date of his passing away.

It has been the writer's privilege, as Secretary of this Society, to be intimately associated with Mr. Dixon in relation to its numerous activities where his sound judgment and constructive suggestions were not only helpful, but of the greatest intrinsic value.

His interest in the Society as an organization was deep-seated and very real, and it would be impossible to give an adequate appreciation of the service which he rendered. He served on the Finance Committee for ten years, for over eight years as chairman. During this period, the income of the Society was nearly doubled; the indebtedness occasioned by the acceptance of the Carnegie gift of the Engineering Building, nearly $100,000, was paid off and the cash surplus of the Society brought up to an excess of $100,000.

It was a part of Mr. Dixon's financial policy and direction that in so responsible and important a work as the Society is undertaking, it should accumulate as an essential part of that responsibility a sufficient cash surplus to provide for unforeseen and unprovided-for expenses of administration (as publications, meetings, etc.), so that their future would be assured beyond any possible doubt.

The Society is one-fourth owner and administrator of real estate worth $2,500,000, besides the publisher of its annual volume of TRANSACTIONS and the monthly JOURNAL, costing annually $100,000.

In this capacity as chairman of the Finance Committee, Mr. Dixon was a most faithful attendant upon the meetings of the Council, invariably contributing the broadest concept of the Society's duties and recognizing that the tech-

[1] A tribute by the Secretary

Wishing to control his own business he organized and established in 1900 the Fawcus Machine Co. at Pittsburgh, manufacturing gears and special machinery and particularly herringbone-gear drives.

Mr. Fawcus was responsible for many inventions, the most notable of which are the machines for cutting herringbone gears, which he started to design and develop in 1912. These machines were patented in the United States and foreign countries.

Mr. Fawcus took an active interest in civic affairs and was a member of the Chamber of Commerce and of the Manufacturers' Association of Pittsburgh. He was also a member of the Engineers' Society of Western Pennsylvania. He became a member of our Society in 1913. He died on January 22, 1918.

JOHN D. FORD

John D. Ford, Rear Admiral (retired) in the United States Navy, died at his home in Baltimore on April 8, 1918.

Admiral Ford was born on May 19, 1840, in Maryland and was educated in the public schools of Baltimore. He was graduated from the Maryland Institute School of Design in June 1861, receiving the Peabody Prize. The following year he was graduated from the Potts School of Mechanical Engineering and immediately entered the United States Navy as third assistant engineer. Early in 1864 he was made second assistant engineer and two years later became first assistant engineer. On December 27, 1890, he was made chief engineer.

During the Civil War Admiral Ford took part in the recapture of Baton Rouge, La., in March 1863, and in the Battle of Mobile Bay, 1864, and was on the *Arizona* when it was destroyed by fire off Poverty Point in the Mississippi River in 1865. He was wrecked in the *Sacramento* on the Coromandel coast of India in 1867.

In 1884 he was put on detached service for the purpose of establishing the Baltimore Manual Training School. From 1894 to 1896 he was connected with the Maryland Agricultural and Mechanical College. He was next assigned to the U. S. S. *Brooklyn*, with the relative rank of commodore, and in 1898 to the U. S. S. *Baltimore* (flagship), later becoming fleet engineer of the Pacific Station. He joined the Asiatic fleet and took part in actions of April 30, May 1 and August 13, 1898, and in the destruction of the Spanish fleet off Cavite, the destruction of the batteries at Cavite and at Sangley Point, the capture of the forts at Corregidor and the capture of Manila. On May 19, 1905, he retired from the service as Rear Admiral.

Admiral Ford was a member of the Associated Veterans of Farragut's Fleet, the Loyal Legion, the Society of Manila Bay, and of the American Society of Naval Engineers. He became a member of the A.S.M.E. in 1884.

SAMUEL AMBROSE FRESHNEY

Samuel A. Freshney was born in January, 1867, in London, England. He was brought to this country when but a child and the family settled in Ohio. His first work was in connection with the electrical business when he was employed by the Brush Electric Co., Cleveland, Ohio. He spent his apprentice-

ship in the shops of this company and was then promoted to the engineering department. After seven years' service he left to become manager of the Electric Light & Power Co., Muskegon, Ill., where he remained until 1900. For the next two years he was branch manager of the Wayne Electric Works at Cincinnati, Ohio, and Grand Rapids, Mich. In 1902 he was made general manager of the Muskegon Traction & Lighting Co., operating street railway, electric and gas properties, and continued in that capacity until 1905, when he was offered and accepted the position of secretary and general manager of the Grand Rapids Board of Public Works, where he had charge of the water works, electric-light systems, public improvements, streets, sewers, flood protection, etc. In 1912 he resigned from the Board of Public Works to become general manager of the Consumers Power Co., Grand Rapids, Mich., which position he held up to the time of his death, September 16, 1918.

Mr. Freshney became a member of the Society in 1913.

JOHN DOLAN GABOURY

John D. Gaboury was born in Knoxville, Tenn., on June 3, 1879. Upon the completion of his collegiate education he took a two-year special course in mathematics at St. Charles Borromée College, Sherbrooke, Quebec, Canada, and followed this in 1895 with a six months' special course in applied electricity at McGill University, Montreal.

Until about 1897 he was associated with his father who was one of the pioneer electric contractors and power-plant operators in the South. His next position was with the Greenville Light & Power Co., Greenville, Miss., as engineer, where he remained until 1905, holding successively the positions of electrician and superintendent. In 1905 he became connected with the Alabama City, Gadsden & Attalla Railway Light & Power Co., Attalla, Ala., as general manager and remained with them for a little over two years, during which time he designed and built a modern condensing steam-turbine power plant for lighting and railway service. In 1907 he entered the employ of the Woodward Iron Co., Woodward, Ala., as electrician, later becoming chief electrical engineer and finally superintendent of power, which position he had been holding for the last four years. The company makes approximately 1500 tons of pig iron per day, furnishing all of its own raw material. This involves the operation of several coal mines, red-ore mines, coal washers, by-product coke plants and a steam railroad for the transportation of raw material to the furnace plant. Mr. Gaboury was entirely responsible for the design, construction and operation of all the power-plant equipment, steam and electric hoists, haulage, rolling stock, steam and electric, as well as all of the repair work involved.

Mr. Gaboury became an associate-member of the Society in 1917 and was particularly active in the affairs of the Birmingham Section. He was also an associate-member of the American Institute of Electrical Engineers. He died very suddenly on May 17.

FRANCIS E. GALLOUPE

Francis E. Galloupe was born in Lynn, Mass., on October 3, 1855. He attended the high school in Lynn and later the Massachusetts Institute of Tech-

nology at Boston, where he took the course in mechanical engineering and received his degree in 1876.

Upon graduation he was connected with the Rhode Island Locomotive Works for about two years and spent approximately the same time with the Baldwin Locomotive Works and with the Brooks Locomotive Works. The next two or three years he devoted to the design of rolling stock for the proposed Meigs Railroad. Following this period he was engaged in the real-estate business. He was interested in developing and redeveloping properties and handled some very important transactions along this line. He possessed an unusually complete system of recording engineering information.

Mr. Galloupe was a charter member of the Society. He died in Boston, January 5, 1918.

FRANK E. GETTS

Frank E. Getts was born in Fort Wayne, Ind., in June 1870, and was educated in the public schools there. From 1887 to 1892 he served his apprenticeship as machinist in the Wabash Railway Shops, Fort Wayne, and for the next three years was connected with the Fort Wayne Electrical Works, first as electrical apprentice and later as construction foreman. His next position was with the Siemens & Halske Electric Co., where he had charge of building and installing electrical generators. He was also with the Northwestern Elevated Railway Co. for a short while. When he became associated with the Chicago Edison Co. in 1903 he was given charge of the installation of all steam turbines at the Fisk Street Power Station. The success of this work was due in great measure to Mr. Getts' personal efforts and his engineering ability. From 1910 to 1913 he had direct charge of all steam work for the General Electric Co. in the Middle West. In October, 1913, he resigned from that company to become general manager of the Chicago office of the Alberger Condenser & Engineering Co., and in April 1915 he became general manager of the Electrical Engineers Equipment Co., Chicago, which position he held at the time of his death, May 7, 1918.

Mr. Getts was a member of the American Institute of Electrical Engineers, and of the Electric Club and Press Club, Chicago. He became a member of the Society in 1913.

MICHAEL JOSEPH GOLDEN

Michael J. Golden was born on November 17, 1862, in Stratford, Ont., Canada. He received his early education in the schools of Lawrence, Mass., and later attended the Massachusetts Institute of Technology for two years as a special student. He served an apprenticeship with William McCartney in Lawrence and was for six years assistant to E. Lyford.

For one year he was an instructor in mechanical drawing at a high school in Hyde Park, Mass. In 1884 he became connected with Purdue University, Lafayette, Ind., as an instructor in shop work, later receiving his degree in mechanical engineering from the University. From 1889 until June 1916, when ill health compelled his resignation, he served as professor of practical mechanics at Purdue, and from 1907 was also director of the practical mechanics laboratory. He was considered an authority in shop management and shop experience and his course of shop lectures was widely known. He spent much

of his time in research, investigating microscopically the structure of wood, for this purpose designing and building much special apparatus.

Professor Golden was the author of several works on mechanics and of a number of shorter articles which appeared in the technical press. He was a member of the Indiana Academy of Science, the American Society of Naval Engineers and the Manual Training Teachers' Association of America. He became a member of the Society in 1892. His death occurred on December 18, 1918.

THEODORE H. GUETHING *

Theodore H. Guething, Lieutenant in the Ordnance Department of the U. S. Army, was born on October 15, 1891, in Winchester, Mass., where he received his early education. He attended Exeter Academy for three years and then entered the Massachusetts Institute of Technology, from which he was graduated in 1915 with the degree of B.S.

He was connected for short periods with the Haughton Elevator Co., Toledo, Ohio, and with the Anaconda Mining Co., Anaconda, Mont. In June 1916, he became associated with the John A. Stevens Engineering Co., Lowell, Mass., where he was assistant in the analysis of the power plant of the Stevens Manufacturing Co., Fall River, Mass., assistant superintendent of the construction of the power plant for the North & Judd Manufacturing Co., New Britain, Conn., and assistant engineer on motoring, Chelsea Fibre Mills, Brooklyn, N. Y.

When the United States entered the War he offered his services to the Government and was commissioned a first lieutenant in the Ordnance Department of the Army. He was assigned to the Picatinny Arsenal, Dover, N. J., as mechanical engineer in charge of the shops and as motor-transport officer, and was working in this capacity when he contracted influenza-pneumonia and died on October 16, 1918.

Lieutenant Guething became a junior member of the Society in 1917.

JULIAN G. GUITERAS*

Julian G. Guiteras, Captain, Engineers' Corps, A. E. F., France, died of pneumonia on October 12, 1918, in Base Hospital No. 15, Chaumont, France. Captain Guiteras was born in New York City on November 14, 1889. He was educated in the city schools, later attending Columbia University from which he was graduated in 1913 with the degree of M.E.

His first position was with the Cadillac Motor Car Co., Detroit, Mich., where he attended their school of applied mechanics, worked through the apprentice course and became draftsman in the electrical department. In October 1915 he became connected with the Hall-Scott Motor Car Co., West Berkeley, Cal., as draftsman, his duties dealing with the designing and testing of aviation engines and propellers, standardization of parts and the systematizing of drafting-room records.

In January 1917 Captain Guiteras passed successfully an examination for a second lieutenancy in the Regular Army, and upon receiving his commission was ordered to Fort Leavenworth for training. Upon the completion of his course there he received a first lieutenant's commission and was sent to Vancouver Barracks, Washington, whence he sailed for France in December

1917 with a captain's commission. In France he was instructor in pioneering in the Pioneer School of Chatillon-Sur-Seine and was later ordered to bridge reconnaissance work. It was while on this work that he contracted influenza which developed into pneumonia.

Captain Guiteras became a junior member of the Society in 1916.

LAURENCE RICHARD GULLEY

Laurence R. Gulley was born at Mason, Mich., on August 14, 1888. He attended the University of Illinois, receiving in 1910 his B.S. degree in mechanical engineering (M.S. in 1911; M.E. in 1917). From 1908 to 1911, during his vacations, he was connected with the Burr Co., Champaign, Ill., as draftsman.

Upon graduation he was employed by the same company and from 1911 to 1913 he served as chief engineer. In 1913 he became general manager of the firm and at the time of his death, October 24, 1918, in addition to holding this position, was also secretary of the Burr Co.

A short while previous to his death Mr. Gulley had designed and built the Gulley tractor dynamometer, which has proved of much interest to tractor-manufacturing concerns.

Mr. Gulley was a member of the honorary societies of Tau Beta Pi and Eta Kappa Nu. He became an associate-member of the Society in 1917.

EDWARD MCKIM HAGAR

Edward M. Hagar was born on June 21, 1873, in Salem, Mass. He was graduated from the Massachusetts Institute of Technology in 1893 with the degree of M.E., and in 1894 received his M.M.E. from Cornell University.

The following year he was employed by the North and West Chicago Street Railroad in their electrical engineering department. In 1895 he became manager of the Chicago office of the Southwark Foundry & Machine Company, and in 1898 founded the firm of E. M. Hagar & Co., western agents for a number of firms handling engines and machinery. In 1899 he was appointed manager of the cement department of the Illinois Steel Co. In 1904 Mr. Hagar became president of the Universal Portland Cement Co., a subsidiary of the U. S. Steel Corporation, and in 1916 president of the Wright-Martin Aircraft Corporation and the Simplex Automobile Co. The following year he was elected president of the American International Steel Corporation.

Mr. Hagar was a member of the American Society of Civil Engineers and of many clubs. He joined the Society in 1895. He died on January 18, 1918.

CLAUDE P. HAYNES

Claude P. Haynes was born in Ellsworth, Litchfield Co., Conn., on September 3, 1888. He attended the Rochester Mechanics' Institute for three years and later entered Syracuse University, taking the regular mechanical engineering course.

He served his apprenticeship as machinist with the General Electric Co., West Lynn, Mass., and was next with the American Optical Co., Southbridge, Mass., as draftsman. He held positions with the General Electric Co., Erie,

Pa., where he designed the tools for a 175-hp. 8-cylinder gasoline motor; with the A. G. Gilman Printing Co., as chief engineer, designing two large rotary presses, folding and paper-handling machinery; with the Aetna Chemical Co., Pittsburgh, Pa., the Tranter Manufacturing Co., in the same city, as engineer salesman on power and power-transmission machinery; with the Aluminum Castings Co., Buffalo, N. Y., as chief engineer of their Niagara plant, and with the Curtiss Aeroplane & Motor Corporation as production engineer.

At the time of his death, October 4, 1918, Mr. Haynes was holding the position of engineer in the research division of the Chemical Warfare Service in Washington, D. C.

Mr. Haynes became a junior member of the Society in 1916.

JOSEPH W. HENDERSON

Joseph W. Henderson was born on February 22, 1869, in Millbrook, Ontario, Canada, and was educated in the schools of Jackson, Mich., receiving private instruction in chemistry and metallurgy.

His first position was in the laboratory of the North Chicago Rolling Mill Co. (later the Illinois Steel Co.), where he worked from 1887 to 1894, when he became connected with the Griffin Wheel Co., Chicago, as chief chemist in charge of the melting operations in making car wheels. The year 1899 he spent with the Crane Manufacturing Co., Chicago, as assistant to the chief chemist in the malleable-iron department. The following year he became associated with the Maryland Car Wheel Works, Baltimore; he was with this firm for four years, the last two as superintendent of the plant. In the fall of 1904 Mr. Henderson accepted the position of superintendent of the Central Car Wheel Co., McKees Rocks, Pa., and the following year became general manager of the Butler Car Wheel Co., Butler, Pa., where he had entire charge of the designing, building and operation of the plant.

In 1907 Mr. Henderson became vice-president of the Gulick, Henderson Co., New York. At the time of his death, December 19, 1918, he held the position of chief of the Bureau of Smoke Regulation, City of Pittsburgh.

Mr. Henderson was a member of the Railway Club of Pittsburgh, the American Foundrymen's Association and the Chamber of Commerce of Pittsburgh. He became a member of the Society in 1916.

CHARLES HARVEY HILE

Charles H. Hile was born at Bellefonte, Pa., in March 1864. He was graduated from Pennsylvania State College in 1892 with the degree B.S. and in 1893 he received the degree of M.E. from the University of Wisconsin.

He then entered the employ of the Philadelphia Traction Co., first as electrical assistant, then as engineer and inspector of underground conduit construction and later as operator in the power station. In July 1894 he entered the employ of the West End Street Railway Co., Boston, Mass., and served continuously with that company and its successor, the Boston Elevated Railway Co., for twenty-two years. During his long career with the two Boston companies, he won rapid promotions, being successively assistant superintendent of wires, superintendent of wires, assistant to the vice-president and

chief of maintenance. In the last-named position he was in charge of the departments of mechanical and electrical engineering, maintenance of way, rolling stock and shops, building, stores, wires and conduits and power maintenance. Impairment of health finally required him to relinquish these heavy responsibilities and the company gave him an indefinite leave of absence with the privilege of engaging in lighter and less nerve-racking duties. In 1916 he became the secretary of the New England Street Railway Club, Boston, Mass. He was also editor of the publications of the club, *The Street Railway Bulletin* and the *Trolley Wayfinder*.

He became a member of the Society in 1916. He died on June 4, 1918.

HAROLD H. HILL

Harold H. Hill was born in 1875, in Detroit, Mich. He was graduated from Cornell University in 1897 with the degree of M.E. His apprenticeship was spent with the Akron, Bedford & Cleveland Railroad Co., Cuyahoga Falls, Ohio. He obtained his drawing-room and shop experience with the American Ball Bearing Co., Cleveland, Ohio. He was next employed by E. H. Jones & Co., Cleveland, as erecting engineer, leaving that firm to represent in Cleveland the B. F. Sturtevant Co., of Boston, Mass.

In 1901 he became associated with the Erie City Iron Works, Cleveland, as mechanical engineer and district sales agent, acting also as contracting engineer. At the time of his death, October 28, 1917, he was holding the position of district sales manager of the company.

Mr. Hill became an associate of the Society in 1904 and a member in 1915.

HARRY C. HOLCK

Harry C. Holck was born in June, 1887, in New York City. He received his technical education in the Carnegie Technical School, after which he entered the employ of the Keuffel & Esser Co., Hoboken, N. J., as assistant to the chief engineer. In 1908 he became connected with the George A. Ohl Co., Woodside, N. J., where he installed a drafting-room system and took charge of the design of their power presses and embossing machines. The following year he entered the employ of the Niles-Bement-Pond Co., Plainfield, N. J., as a designer, and while with this firm successfully designed a car-wheel lathe to turn car wheels at the rate of two in four minutes. In 1910 he became associated with the General Electric Co., Schenectady, N. Y., as engineer and designer of A. T. B. generators and synchronous and induction motors.

For the next three years he was employed successively by the Otis Elevator Co., New York City, as construction engineer for freight and passenger elevators; by the Regina Co., Rahway, N. J., as assistant to chief draftsman in systematizing and developing the design of a multi-process printing press; and by the Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa., as engineer on control apparatus, rheostats, switchboards and oil switches. In 1913 Mr. Holck became connected with the Public Service Electric Co., Newark, N. J., where he was engaged in the design and engineering of sub-stations and central stations, system of railways and lighting distribution, and developed one of the largest and most modern stations in the East.

At the time of his death, June 13, 1918, he was employed as engineer and electric designer in the engineering department of the company. Mr. Holck became a junior member of the Society in 1916.

STEPHEN PAUL HOSKINS *

Stephen Paul Hoskins, 319th Infantry, A. E. F., was killed in action on November 2, 1918, in one of the battles of the Argonne Forest and lies buried near the little town of Imecourt.

Lieutenant Hoskins was born on May 22, 1891, in Erie, Pa. He received his education in the grade schools of Pennsylvania and West Virginia, later attending the West Virginia Wesleyan College and the West Virginia University. He was graduated from the latter in 1914 with the degree of B.S. in mechanical engineering. The year following his graduation he was assistant in mechanical drawing in the University, and later instructor in machine design and mechanical drawing.

He left this position to become efficiency engineer with the research division of the Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa., where he remained until June 1916. An attack of inflammatory rheumatism made it necessary for him to sever temporarily his business connections and upon his recovery he entered the service at Camp Lee, Petersburg, Va., in October 1916. He was recommended for the Third Officers' Training Camp and just before leaving for France was graduated as second lieutenant. He was later promoted to first lieutenant for bravery on the field and just prior to his death was recommended for promotion to the grade of captain and for the Distinguished Service Cross.

Lieutenant Hoskins became a junior member of the Society in 1916.

JOHN S. HUNTER

John S. Hunter was born in Manchester, Conn., on June 14, 1834. He was educated in Rockville and in the public schools of Pennsylvania. He served his apprenticeship with the Woodruff & Beach Iron Works, Hartford.

For eleven years he was in charge of the Hartford Pumping Station, later becoming a member of the firm of Hunter & Sanford, machinists. Seven years later the Hartford Foundry and Machine Co. was organized and Mr. Hunter was chosen as president. During his connection with the company he built the largest pumping engine in the world, which was installed for the St. Louis Water Works in 1873. For a number of years Mr. Hunter was with the Henry R. Worthington Co., New York, erecting steam pumps for city water works. He was appointed a member of the Board of Water Commissioners of Hartford in 1870 and served three years. By reappointment he became a member of the board again in 1894 and was president from 1895 to 1899. In 1904 he was appointed fire commissioner and served three years.

Mr. Hunter became a member of the Society in 1889. He died on May 7, 1918.

HENRY SMYTH ISHAM

Henry S. Isham was born in New Britain, Conn., on March 16, 1866, and was educated at Mowry and Goff's English and Classical School, and at the Bryan and Stratton Business College in Providence, R. I.

He first served an apprenticeship of three years with the Harris-Corliss Engine Works, Providence, and then entered the service of the Rhode Island Locomotive Works in the capacity of draftsman. From that position he went as draftsman with the Jeffrey Manufacturing Co., Columbus, Ohio, and in the following year, 1892, he became connected in the same capacity with the Johnson Steel Co., Johnstown, Pa. Mr. Isham's next position was with the Pond Machine Tool Co., Plainfield, N. J., as draftsman. The year of 1895–1896 he was with the Washington, Alexandria and Mount Vernon Railway, and a little later was located in the chief engineer's office of the Central Railroad of New Jersey. For over a year he worked with the Mossberg Manufacturing Co., Attleboro, Mass., leaving that firm to take a position in 1897 with the Metropolitan Street Railway Co., New York City, as track expert in the office of the engineer of maintenance of way. From 1899 to 1901 he was designing draftsman for the São Paulo Railway, Light & Power Co., Ltd., Sao Paulo, Brasil, S. A.

In 1901 Mr. Isham returned to the United States to enter the employ of the Pennsylvania Steel Co., Harrisburg, Pa., remaining there until 1903. From 1903 to 1908 he was chief draftsman with Ford, Bacon & Davis, New York City, and then became associated with the New York Railways Co., where he had charge chiefly of the track work. His next connection was again with Ford, Bacon & Davis as chief draftsman. About the middle of 1918 he entered the service of the New York Edison Co., New York City, and was with that company at the time of his death, which occurred in an accident on November 28, 1918.

Mr. Isham became a member of the Society in 1902.

ROBERT ELLSWORTH JACKSON

Robert E. Jackson was born in Matteawan, N. Y., on August 24, 1888. He was educated in the public schools of Garfield, N. J.

He served his apprenticeship with the Dutchess Tool Works, Fishkill Landing, N. Y., and there learned the machinist's trade. The year of 1910 he spent with the Coldwell Wilcox Company, Newburgh, N. Y., as machinist. He then worked in the same capacity for about six months with the Fiat Automobile Company, Poughkeepsie, N. Y. Upon leaving this company he became associated with P. H. Gill & Sons, Brooklyn, N. Y., as machinist. In April 1911 he entered the employ of the Edison Laboratory, West Orange, N. J., as foreman of the machine department. He was later made superintendent and held this position at the time of his death.

Mr. Jackson became a junior member of the Society in 1917. He died at West Orange, N. J., on April 5, 1918.

ARTHUR IRVING JACOBS

Arthur I. Jacobs was born in Hebron, Conn., in 1858. His educational advantages were meager during his boyhood and after his ninth year his schooling was limited to a short period in the winter. He worked with his father in mechanical lines until he attained his majority, when he secured employment in the Knowles Loom Works, Worcester, Mass. His mechanical bent soon displayed itself and in a short time he made great improvements in the manu-

facturing methods of making harness chains for looms. He remained with this firm until 1887, during which period he invented and built a book-sewing machine, of which several were purchased by Boston bookbinders. The Smyth Manufacturing Co., Hartford, Conn., which also manufactured such machines, became interested in his inventions, purchased his patents and engaged him to go to Hartford and he remained with them until 1901. During this period he invented and developed several machines for bookbinding; among these were two machines for making book covers which marked a great advance over methods which had been employed.

In 1902 he invented an improved drill chuck which he patented in the fall of that year. The following year the Jacobs Manufacturing Company was incorporated and has expanded from a small business to a large and active concern, of which he was president at the time of his death.

Mr. Jacobs became a member of the Society in 1913. He died on February 16, 1918.

FRANK CAZENOVE JONES

Frank C. Jones was born in Washington, D. C., on June 14, 1857. He was graduated from the University of Virginia and then attended Stevens Institute of Technology where he received his M.E. degree. His first two years upon graduation were spent with the Baldwin Locomotive Works. In 1879 he became connected with the Delaware Bridge Co., and was next employed as mechanical expert and superintendent of factories for the New York Belting & Packing Co. Somewhat later he became manager of the International Okonite Co. For a number of years he was also president of the W. A. Underhill Brick Co., New York. Mr. Jones organized the Manhattan Rubber Manufacturing Co. in 1893 and was president of this company for ten years, at which time ill health compelled his retirement from active work. At the time of his death, September 19, 1918, he was a director of the Lubricating Oil Co., and chairman of the Okonite Co., New York. Mr. Jones became a member of the Society in 1891.

PAUL JONES

Paul Jones was born in Wilmington, Del., on May 11, 1881, and was educated in the schools of that city, later attending the Heath School. He studied as a special student in mechanical and mining engineering and in 1902 took a position with the Diamond Steel Co., Wilmington, where he was engaged in general drafting for iron- and steel-works equipment, later becoming engineer of tests and then assistant to the superintendent of shops and steel products.

In 1906 Mr. Jones became connected with the E. I. du Pont de Nemours Co., Wilmington, in the light, power and heat division. His duties were in the general office and in field engineering work in connection with construction, design and maintenance of power plants and power-transmission systems and costs. His next position was in 1909 with the H. C. Frick Co., United States Steel Corporation, Pittsburgh, Pa., as assistant engineer for the design of coal and coke plants, railroad trackage and structures, power plants, etc. For the year 1910 to 1911 Mr. Jones's services were loaned to the G. S. Baton Co., as construction engineer, where his duties were along the same lines as they had been with the Frick Co. He returned to the employ of the Frick Co. and was

made plant superintendent of the Filbert Works. He completed this plant, developing and maintaining all plant operations.

In 1914 he became associated with the Bosch Magneto Co., Plainfield, N. J., as works engineer. He was engaged in the design, construction and maintenance of buildings and equipment and the direction of power-plant systems. In the spring of 1918 he was commissioned a first lieutenant in the Aviation Section, Signal Reserve Corps, of the Army and was assigned to duty in the finance department. At the time of his death, December 17, 1918, he was connected with the Air Nitrates Corporation, New York, having been honorably discharged from the service.

Mr. Jones was a member of the American Institute of Mining Engineers. He became an associate-member of the Society in 1917.

GEORGE ALEXANDER JUST

George A. Just was born in 1860 in New York City. He attended Rensselaer Polytechnic Institute, from which he was graduated in 1881 with the degree of C.E. He was first employed by the Phoenix Iron Works, and then was connected with the New Jersey Steel and Iron Co., Trenton, N. J., later acting as engineer for that firm in New York. He was also chief engineer of the Jackson Architectural Iron Works, afterward becoming a member of the firm Lewison & Just, consulting engineers.

Mr. Just was a pioneer in the steel industry and was at one time associated with Cooper, Hewitt & Co., and was one of the first engineers to develop the modern steel-frame building. At the time of his death, December 27, 1918, he was president of the George A. Just Co. He took an active interest in politics and was the engineer member of the commission which framed the Code of Building Laws for Greater New York, and from 1907 to 1915 served as chairman of the Board of Examiners of New York.

He was a member and ex-director of the American Society of Civil Engineers. He became a member of the Society in 1904.

WILLIAM J. KEEP

William J. Keep, for many years consulting engineer for the Michigan Stove Co., Detroit, and one of the best-known writers of the country on foundry topics, died on September 30 following an accident, when he was knocked to the pavement by a street car and sustained fatal injuries.

Mr. Keep was born in June, 1842, in Oberlin, Ohio. He attended Oberlin College for his freshman and sophomore years and was graduated from Union College, Schenectady, N. Y., in 1865 with the degree of civil engineer. He served an apprenticeship with the Globe Iron Works, Cleveland, and obtained his shop experience with Fuller, Warren & Co., Troy, N. Y. From 1865 to 1868 he was employed by Hubbell & Brothers, Buffalo stove manufacturers, when he became associated again with Fuller, Warren & Co. and was with them for about eight years. During the years of 1872 to 1877 he delivered a course of lectures to the senior class of Rensselaer Polytechnic Institute. From 1875 to 1884 he manufactured stoves on his own account in the city of Troy.

In 1902 his treatise on Cast Iron was published, which is the best known of his writings. In 1885 Mr. Keep brought out some results of his studies of the relation between the shrinkage of cast iron and the composition of a foundry mixture. Later he devised a method and apparatus known as "Keep's Test," which he later named "Mechanical Analysis," for the determination of shrinkage in cast iron, and in this way to regulate the cupola mixture. For this purpose he used a ½-in. test bar. He elaborated his method of testing after making many thousands of tests in the investigation of the relation between the chemical analysis of cast iron and its physical properties, and the results were embodied in his writings.

Mr. Keep became a member of the Society in 1893 and from 1903 to 1905 was vice-president. He was also a member of the American Institute of Mining Engineers, the (British) Iron and Steel Institute, the International Association for Testing Materials, the American Foundrymen's Association, the American Association for the Advancement of Science, the Detroit Engineering Society (Past-President), honorary member of the Rensselaer Society of Engineers, and The Franklin Institute.

WILLIAM KENT

William Kent was born in Philadelphia on March 5, 1851. He was educated in the schools of that city, and later, while employed with the Jersey City Gas Company, he attended the night classes of Cooper Union, New York City, for a period of five years. He then became connected with the Ringwood Iron Works, Hewitt, N. J., where he obtained considerable practice in engineering and chemistry, remaining with this concern until 1874. Becoming convinced of the necessity of further education, he entered Stevens Institute of Technology, first as a special student in chemistry, and later, at the instance of the late Dr. Robert H. Thurston, enrolled himself in the senior class, graduating in 1876 with the degree of mechanical engineer. In June 1875 he was appointed assistant to Dr. Thurston in the work of the United States iron and steel testing board and under his supervision carried on a two-year research on the properties of copper-tin and copper-zinc alloys.

From 1877 to 1879 he was editor of the *American Manufacturer and Iron World* of Pittsburgh, resigning to become superintendent of the open-hearth of Schoenberger and Company, Pittsburgh. Leaving the steel business in 1882, he took charge of the Babcock and Wilcox Company's Pittsburgh office. It was at this time that he formed a partnership with Wm. F. Zimmerman, known as the Pittsburgh Testing Laboratory, which later was sold to Hunt and Clapp. Later Mr. Kent was made superintendent of sales and engineer of tests of the Babcock and Wilcox Company and was transferred to the New York office. While with this company he made numerous inventions on boilers, furnaces and boiler accessories. In 1887 he became general manager of the U. S. Torsion Balance and Scale Company and developed the methods and machinery for building this highly sensitive scale now generally used in the drug trade.

In 1891 Mr. Kent began practice as a consulting engineer in New York City and in 1895 became associate editor of *Engineering News*, a connection continued until 1903, at which time he was offered and accepted the position

of dean of mechanical engineering in the L. C. Smith College of Applied Science in Syracuse University. He remained at Syracuse until 1908, when he became general manager of the Sandusky Foundry and Machine Company, Sandusky, Ohio. In 1910 he resumed his consulting engineering practice and at the same time became contributing editor to *Industrial Engineering*.

Mr Kent was an organization member of the Society, and Vice-President from 1888 to 1890. He was preëminently versatile, an original thinker, a ready speaker, an author and frequent contributor of papers and technical articles, and an engineer whose services were much in demand in a consulting capacity or as an expert in patent cases. He was a regular attendant at the Annual and Spring Meetings, and probably contributed more largely to the discussion of the various papers than any other member, besides being the author of no less than 12 papers, a number of which were noteworthy contributions to engineering knowledge.

As the author of the Mechanical Engineer's Pocket-Book his name became known among engineers the world over, and through this medium he rendered an almost incalculable service to the engineering profession. For many years Mr. Kent had followed the practice of clipping and filing data on engineering subjects, and this material was made the basis of the first edition of his book in 1895. At that time practically the only American engineering pocketbooks were Trautwine, in the civil engineering field, and Haswell, largely mechanical, but dealing with engineering of an earlier day when rule-of-thumb rather than research was the main reliance. In Kent's book the practice was followed of summarizing the data and giving the sources of authority, so that any of the subjects could be investigated further.

Besides his Mechanical Engineers' Pocket-Book, Mr. Kent was also the author of Steam Boiler Economy, Investigating an Industry, Bookkeeping and Cost Accounting for Factories, as well as papers presented before the numerous technical societies of which he was a member, and articles contributed to the technical press. He was a lecturer at many colleges and technical schools, including Yale, Cornell, University of Illinois, West Virginia University, Stevens Institute, Brooklyn, Franklin and Worcester Polytechnic institutes, and many others.

Mr. Kent was regarded as an authority on steam-boiler practice and on shop management. He was an earnest advocate of the principles of scientific management as enunciated by Frederick W. Taylor and was one of the charter members of the Taylor Society. He was also an inventor and designed the wing-wall furnace to secure complete combustion where there was not room for the Dutch-oven furnace, and developed a gas producer similar to the Dawson, but entirely independently of the latter. Singularly, his American patents and the English Dawson patents were issued on the same day. Many other inventions and devices are to his credit.

He was also engaged upon numerous investigations, notably work for the Babcock and Wilcox Company on high-volatile coals, for the New York Edison Company on smoke abatement, and in New Jersey with regard to certain water rights. Latterly he devoted much of his time to patent cases as an expert.

Besides his membership in this Society, he was a member of the American Society of Heating and Ventilating Engineers, of which he was president in 1905; American Institute of Mining Engineers; Society for the Promotion of Engi-

neering Education; American Association for the Advancement of Science, and a number of others. He was a member of the Power Test Committee of the A.S.M.E. In 1907 he received the degree of Doctor of Engineering from Syracuse University. He died on September 18, 1918.

WILLIAM R. KING *

Major William R. King, Ordnance, U. S. Army, who died at the Post Hospital, Army Proving Ground, Aberdeen, Md., July 18, 1918, was born in New York City in 1864.

Prior to the entrance of the United States into the European War, Major King had been an active advocate of preparedness and published an article, A National Factor of Safety, in the *Engineering Record* of January 20, 1915, one of the first comments on the indispensable function of the engineer in modern war and the duty of technical schools to teach military engineering.

Major King was graduated from Stevens Institute of Technology with the class of 1886 and was chairman of the special committee which organized the battalion of 400 Stevens alumni and students in the Preparedness Parade, May 13, 1916. Later he was chairman of the Stevens Alumni Military Committee, placing 250 mechanical engineers in the reserve and civilian service. He, himself, applied for a commission on March 22, 1917.

On October 6, 1917, he was selected for the exceptional duty of Chief of Design and Construction of the new Army Proving Ground at Aberdeen, with its great variety of structures — railroads, highways, docks, power plant, machine shops, gun emplacements, ammunition storehouses and dwellings. He had supervised the erection of a part of the permanent structures and completed much of the temporary work at this proving ground when, on July 17, he was informed of prospective transfer to command at another proving ground and of recommendation for his promotion to the rank of Lieutenant Colonel. Early in the evening of the same day Major King was fatally shot in his room by a man who had apparently no motive except a fancied grievance.

The following is a record of his principal engineering responsibilities: His first important position was that of assistant superintendent with R. Hoe & Co., New York City, 1886 to 1890; from 1890 to 1894 he was manager and engineer of the Empire State Phosphate Mining Co., an interest of Cooper Hewitt & Co. in Florida; he was next consulting engineer of companies developing respectively an air brake and the King Wyatt resistance type of electric furnace, 1894 to 1897; from 1897 to 1901 he was superintendent and manager of construction of the Oxnard Construction Co., erecting the beet-sugar factories at Oxnard, Cal., at Ames, Neb., and at Rocky Ford, Cal. Thereafter, from 1901 to the time of the war his work was in the field of hydraulic engineering; in particular, the electric plant of the Stanislaus River in California, the Klickitat River development in Washington and the irrigation and electrification projects of the Northern Pacific Railroad Co.

Major King became a member of the Society in 1914.

JOSEPH FREDERIC KLEIN

Joseph Frederic Klein was born in Paris, France, on October 10, 1849. His parents were Huguenots and came to America when he was two and a half years

old. They first settled in Bridgeport, Conn., where he attended the public schools, and moved to New Haven in 1858, where he attended the Eaton Grammar School. After finishing his common-school education he was employed as a machinist in the New Haven shops. Later, in 1866, he attended the famous military school of Gen. William H. Russell, which was also a college preparatory school. He was employed by Sargent & Co. and the W. & E. T. Fitch Co. as salesman and shipping clerk, always studying during his spare moments, as he was determined to get a college education.

His studious disposition won him many friends, among whom was the distinguished Prof. Willard J. Gibbs, of Yale University, who took a personal interest in him and through whose influence he decided to enter Sheffield Scientific School of Yale University. This he did in 1868, taking the course in mechanical engineering, then called dynamic engineering, and being graduated with the degree of Ph.B. in 1871. One of his classmates was Mansfield Merriman, afterward his associate at Lehigh University as professor of civil engineering. He was appointed the first instructor of the first evening school started in New Haven in 1868.

From 1871 to 1873 he did experimental work for Prof. W. P. Trowbridge of Yale and others. He also took a graduate course in mechanical engineering, receiving the degree of D.E. (Dynamic Engineer) at Sheffield in 1873. He entered the employ of Colt's Armory, Hartford, Conn., in 1873, first as draftsman and finally as assistant to the chief engineer, Mr. Charles B. Richards, that company being engaged at the time on work connected with the heating and ventilating system of the (then) new State Capitol at Hartford. Mr. Richards, the inventor of the Richards steam-engine indicator, later became chief engineer of the Southwark Foundry and Machine Co., of Philadelphia, and subsequently professor of mechanical engineering at Yale University. Professor Klein was in the employ of Colt's from 1873 to 1877.

In 1877 Professor Klein returned to Sheffield Scientific School as instructor in mechanical engineering, being the assistant in this department of the late Prof. A. Jay DuBois. In the fall of 1881 he was called to Lehigh University to establish and develop a course in mechanical engineering, and was connected with that institution up to the time of his death. In 1887–1888 he was secretary of the faculty. In addition to his duties as head of the mechanical engineering department he was appointed dean of the faculty in 1907, which additional work he performed with distinction. From February to April 1910 he was acting president of the University.

Professor Klein's published books are: Mechanical Technology of Machine Construction, 1884; Elements of Machine Design, 1889; Table of Coördinates for Laying Out Accurate Profiles of Gear Teeth, 1889; The Design of a High-Speed Steam Engine, 1892; and The Physical Significance of Entropy or of the Second Law, 1910. Also the following translations from the German: Weisbach-Herrmann's Mechanics of Machinery of Transmission, 1883; Zeuner's Treatise on Valve Gears, 1884; and Zeuner's Technical Thermodynamics, 1907. He spent a number of years in researches on Dynamics of the Shaft Governor, intending to issue a work on flywheels and governors; this was never completed, although a part of the results of his investigations are in use in the mechanical engineering course in Lehigh. He also made extensive researches in Kinematics of Machinery. His magazine articles are: Absolute Zero of Temperature, Ves

Engineering Magazine, April, 1880, vol. xxxii; Concerning $(T_1 - T_2)/T_1$ Limit of Efficiency of Heat Engines, *Journal of the Franklin Institute*, April, 1879; Table and Diagram for Determining the Diameter of Speed when Connected by an Open Belt of Constant Length, *Journal of the Franklin Institute*, May, 1880; Cone Pulley Diameters, No. 2, *American Machinist*, October 22, 1881; The Law of Proportional Resistance, *Journal of Engineering Society of Lehigh University*, November, 1889; and New Construction of the Force of Inertia of Connecting Rods and Couplers, and Construction of the Pressures on Their Pins, *Journal of The Franklin Institute*, September-October, 1891.

With Mr. L. P. Breckenridge, then his assistant at Lehigh University, now professor of mechanical engineering at Sheffield Scientific School of Yale University, he conducted a series of tests for the Lehigh Valley R. R. Co. during the summer of (probably) 1888. Among other purposes the tests were to determine the relative performance value of three different types of locomotive valves, the plain slide valve, the Allen-Richardson balance valve and the piston valve. Incidentally measurements were made of the exact length of the road, and they showed the official record to be a half mile in error.

Professor Klein was elected to membership in the Society in 1881, one year after its organization, and in 1907, on the occasion of the celebration of his twenty-fifth anniversary at Lehigh, he was presented by the alumni of his department of the University with a life membership in the Society. He was an honorary member of Tau Beta Pi. He died on February 11, 1918.

OCTAVIUS AUGUSTUS LAW

Octavius A. Law was born on October 27, 1872, in Philadelphia, Pa., and received his education in the public schools of that city. He served his apprenticeship with William B. Smith, a general contractor of Philadelphia, later becoming his estimator, draftsman and foreman of erection of numerous public buildings. In 1899 he became connected with the Midvale Steel Co., Philadelphia, as assistant to the chief engineer and had entire charge of all furnace and building construction. He was with this company at the time of his death, October 26, 1918.

Mr. Law became an associate of the Society in 1915.

HENRY LÉAUTÉ

Henry Léauté, eminent French engineer and mathematician, was born in 1847. In 1866, at the age of 19, he had the unique distinction of being accepted at the head of a long list of competitors for entrance into two of the best technical schools in France, the École Polytechnique and École Normale. He entered the latter and was graduated in 1869 with the degree of engineer.

The war of 1870 naturally interrupted his professional career, but, released from military service in 1871, the young man at once engaged in three lines of work requiring very dissimilar characteristics of mind — those of medicine, mathematics and mechanics, and rapidly established an important position for himself in each of these branches of science.

The first paper published by Léauté dealt with partial derivative equations of the first order. Of much greater importance was the second paper, dealing with friction in bearings. Other of his works covered the subjects of general kinematics, strength of materials, dynamics and theory of machines. In all of this work he made extensive use of higher mathematical methods in the solution of mechanical problems. It is significant, however, that in all his work he carefully avoided the use of mathematics for its own sake and never lost sight of the practical applications of his investigations.

In kinematics, Léauté introduced a new conception, namely, the order of proximity of two arcs of neighboring curves. Because of this concept he was enabled to formulate precise mathematical rules to take the place of former approximations, and these he applied in the design of gears and in the improvement of Watt's parallelogram and the Farcot governor.

In the field of the strength of materials, Léauté developed important data in relation to the elastic deformation of circular members and the distribution of stresses in cylindrical bands, especially in band brakes. Of the greatest importance, however, were his master papers dealing with dynamics and the theory of machines. His treatise on Teledynamic Transmission has become a classic. The transmission of power at a distance by means of cables was fully solved by him, both from the theoretical and practical points of view. The great importance of this work has failed to be realized only because the introduction of electric transmission has materially reduced the field of application of cable transmission.

The governing of engines formed the subject of several papers of great importance. Starting with the study of flyball governor, he gradually passed to that of oscillations having long periods and investigated the whole field, applying new and ingenious mathematical methods.

In addition to his scientific work, Léauté took a prominent part in national educational activities, and also in business, where he held important positions, such as that of president of the French Telephone Company and also of the Paris Electric Distribution Company.

In 1891 he was elected honorary member of The American Society of Mechanical Engineers. In 1915, in spite of the fact that a malignant disease for years had sapped his strength, he took an active part in the management of war industries, on the running of which depended the defense of the country at that time. It is no exaggeration to say that this patriotic activity was the prime cause of his death, which occurred on November 5, 1916.

LEO JULIUS LEFFLER

Leo J. Leffler was born on June 30, 1885, in New York City. He was educated in the public schools of Brooklyn, attending Manual Training High School and later Cornell University, from which he was graduated in 1907 with the degree of M.E.

Upon graduation he entered the corporation of Chas. Leffler & Co., Brooklyn, manufacturers of machinery and dies for the manufacture of tin and sheet-metal ware. He assisted his father, Mr. Charles Leffler, in the active management of the company. He was secretary of the firm and was holding this position at the time of his death.

Mr. Leffler died on December 20, 1918, in Albuquerque, N. M. He became an associate-member of the Society in 1915.

FRANK SHEPPARD LEISENRING *

Frank S. Leisenring was born on January 18, 1887, in Northumberland, Pa. His family moved to Harrisburg, Pa., where he attended the public schools and later the Bordentown Military Academy. He then finished his preparation for Stevens Institute of Technology at the Stevens School, graduating from the latter in 1904. He then entered Stevens and was graduated with the class of 1908.

Upon graduation he entered the employ of the J. F. Shanley Co., contractors, Newark, N. J., and finally became their superintendent. He later went into the railroad supply business for himself under the name of the Mechanical Specialties Co., New York, holding the position of president. For five months after we entered the war he was engaged in inspecting wire for the Government at New Haven, Conn. The last year he devoted to engineering activities in the manufacture of airplanes for the United States Government.

In the latter part of 1917 Mr. Leisenring joined the 22d Regiment, New York State Guard, Company F. He later left Company F and organized a company of engineers, known as Company M, 22d Regiment, New York State Guard, and was connected with this company as Second Lieutenant.

Mr. Leisenring died on October 23, 1918, of pneumonia. He became an associate-member of the Society in 1917.

HARRY SHELDON LEONARD

Harry S. Leonard was born on October 21, 1865, in Washington, D. C. He was educated in the public schools of that city and later attended Yale University, from which he received in 1886 the degree of Ph.B. He was connected for about eight years with the New Haven Wire Manufacturing Co. as manager and then spent about a year with the Trenton Iron Co., Trenton, N. J., as sales manager. For the next three years he conducted his own business in Boston as a manufacturer's agent. In 1899 he became manager of the Boston office of the Westinghouse Electric & Manufacturing Co., leaving that firm to become associated with the Winchester Repeating Arms Co., New Haven, Conn., where he remained till about a year ago, when ill health compelled him to resign from the vice-presidency of the company, with which he had been connected for eighteen years.

Mr. Leonard became a member of the Society in 1916. He died in New York City on July 26, 1918.

ALBERT THEODORE LEONHARD

Albert T. Leonhard, secretary of the Paterson Parchment Paper Co., Passaic, N. J., died on September 29, 1918, a victim of Spanish influenza.

Mr. Leonhard was born on March 4, 1887, in Haledon, N. J. He attended high school in Passaic and later Stevens Preparatory School, from which he went to Stevens Institute of Technology, receiving his M.E. degree in 1908. He became associated in the same year with the Paterson Parchment Paper Co,

where he designed and supervised the construction of paper-making and other machinery, improved old and devised new processes for the manufacture of paper; he also designed and supervised the construction of new mill buildings and had general charge of the mechanical department. At the time of his death he held the position of secretary of the firm.

Mr. Leonhard became an associate-member of the Society in 1916.

THOMAS M. LYNCH *

Thomas M. Lynch, Major, General Supplies Division, Quartermaster Corps, U. S. Army, died on December 18, 1918. He was born on July 2, 1882, in Worcester, Mass., and was educated in the schools of that city, later attending the Worcester Polytechnic Institute.

He was first associated with the Buena Vista Extract Co., Buena Vista, Va., as assistant manager in active charge of operating and executive affairs, later becoming superintendent. His duties covered the designing of mill construction, supervision of the installation, operation and improvement of practically all kinds of conveying machinery, heating and evaporating equipment. His next position was as production engineer with the Babcock & Wilcox Co., Bayonne, N. J. He was also associated for a short period as superintendent with Barrett, Nephews & Co., West Brighton, S. I., and for two years was a staff member of the J. J. Lynch Co., New York.

At the time of his death, Major Lynch was Chief of the Administrative Branch of the General Supplies Division, Quartermaster Corps, having been placed in charge of that department at the time of its creation. He organized this whole division and was appointed to the rank of major from civil life in recognition of his merit and the efficient results he had secured.

Major Lynch became an associate-member of the Society in 1914.

DALE MCCARTY

Dale McCarty was born in Gosport, Ind., on January 19, 1892, was educated in the public schools there and later attended Purdue University, from which he received the degree of M.E. in 1911. Upon graduation he worked for a short period with the Western Electric Co., Chicago. In September, 1911, he became connected with the Santa Fe Railroad Co., Chicago, where his duties consisted of steel detailing, layouts, freight and steel passenger-car designs, inspection of material and sketching of foreign-design cars. In the early part of 1914 he resigned from this position to become draftsman with the Enterprise Railway Equipment Co. His work there in the drafting room called for steel hopper, ore, steel and composite ballast, and drop-bottom gondola-car designs, stress diagrams and estimates of weight having to be prepared for all cars designed. As mechanical representative of the company he had charge of the general inspection and oversight of deliveries of malleable and steel castings. He was also responsible for the inspection and approval of sample cars in conjunction with the representatives of railroads.

Mr. McCarty had expected to enter the Central Officer's Training Camp in January 1919. He was stricken with Spanish influenza while on a business trip and died in Indianapolis, Ind., on October 18, 1918. He became a junior member of the Society in 1916.

OSCAR JOHN MAY*

Oscar John May, Captain in the Signal Corps, United States Army, died on May 22, 1918, at the Washington Sanitarium, Takoma Park, Washington, D. C.

Captain May was born on May 15, 1878, in Chicago, Ill., and was educated in that city and graduated from the Lewis Institute. From 1900 to 1911 he worked with E. B. Ellicott, electrical engineer for the Sanitary District of Chicago, in various capacities — as operating engineer, constructing engineer and as superintendent of the Sanitary District Power House, Lockport, Ill. As superintendent he installed two of the 6000-hp. hydraulic turbines and generators with the necessary electrical equipment. He was next associated with the Texas Company, first as operating and testing engineer, and later as chief engineer of the Chicago district, supervising practical testing and research work on lubricants. In 1914 he was made assistant superintendent of the company and given charge of the designing and rearranging of mechanical conditions directly affected by lubrication.

Captain May entered the Service in June 1917 as a captain in the Engineers' Reserve Corps, and was recommissioned as a captain in the Signal Corps in November 1917 and was assigned to the Lubrication Department. He had full charge of the experimental work necessary in the preparation of specifications covering lubricating oil for aeronautic engines, necessitating very elaborate tests at the Washington Navy Yard, where he had under his direction a corps of army and navy engineers. Very important work was also carried on under his personal supervision at the altitude testing laboratory of the Bureau of Standards, where in the first consecutive tests made Captain May stood continuously a watch of sixty-five hours, indicating his remarkable physical endurance and the tremendous interest and conscientious responsibility he felt in the work. He had full charge of the lubrication engineers and oil-house men recently established in the various aviation fields in this country, and also of the special experimental testing work in connection with lubricants and fuel at Dayton, Ohio, and at the various manufacturing plants.

As an indication of the appreciation of Captain May's ability and service he was recommended by the Chief of the Lubrication Department early in February for promotion to the rank of major.

He was a member of the National Association of Stationary Engineers. He became a member of the Society in 1914.

ERNEST AINSWORTH MOORE

Ernest A. Moore was born in Victoria, Australia, on October 14, 1879. He was educated in Melbourne, Australia, and later received special instruction in work of a mechanical nature from tutors.

While in Australia he was employed by Knox, Schlapp & Co., who represented the Allis-Chalmers Company, in the capacity of private secretary to Mr. William Knox. In 1904 Mr. Moore decided to come to the United States and in August of that year became draftsman with the Filer & Stowell Co., Milwaukee. Two years later he became connected with the Allis-Chalmers Company, working first in the gas-engine department, and later as assistant engineer. In 1908 he became chief engineer of the Bates Machine Company, Joliet, Ill., having

full charge of all technical, and later all commercial engineering, work; he designed built and supervised a great amount of special machinery and while with this company obtained his experience in work of a consulting and legal technical nature.

Mr. Moore left the Bates Machine Company in 1913 to take the position of resident manager in Chicago for the A. M. Byers Company, Pittsburgh, manufacturers of wrought-iron pipe. About May 1914 he left Chicago for Detroit, planning to develop there a new business for the production of a new machine making paper containers. This machine was first designed by him in 1911 and was gradually perfected, until in 1914 the Moore Container Company was organized in Detroit, of which he was president. Plans were practically completed for the manufacture of the machine when his health failed and he was forced to give up his work completely and leave for the West in an effort to regain his strength. He died very suddenly in Phoenix, Ariz., on February 15, 1918.

Mr. Moore became a member of the Society in 1913.

WILLIAM EARLE MOSHER

William E. Mosher, who died of pneumonia in Washington, D. C., on October 12, was assistant superintendent engineer of the Army Transport Service, and had been recommended for a commission as Major in the Quartermaster Corps. He was born in 1888 and attended the schools of Mechanicsville, N. Y. In 1909 he received the degree of Ph. B. from Syracuse University and 1911 the degree of M.E. He then attended the Graduate School of the University of Illinois and obtained his M. S. in 1913, having specialised in refrigeration and thermodynamics. From September 1913 to June 1916 Mr. Mosher was assistant refrigeration technologist, U. S. Department of Agriculture, and had charge of the portable precooling plant. His next position was with the Fruit Dispatch Co., New York, as consulting engineer. In January 1918 he obtained leave of absence that he might offer his services to the Government.

Mr. Mosher was a member of the honorary societies of Phi Beta Kappa, Sigma Xi and Tau Beta Pi. He was also a member of the American Society of Refrigerating Engineers. He became a junior member of the Society in 1912.

JOHN J. MULLANEY

John J. Mullaney was born in Ireland in 1864. He was brought to this country when a child and was educated in the schools of New York City, later attending Cooper Union. His apprenticeship was spent with the Delamater Iron Works, New York, from 1880 to 1884. The next three years he was employed as a machinist and in 1888 he became superintendent of the tool and manufacturing departments of the Columbia Typewriter Co. and the following year was associated with the Smith Premier Typewriter Co. About 1890 he became associated with the Brosius Sewing Machine Co. as superintendent, resigning in 1893 to take a similar position with the Garvin Machine Co. Later he was president of the Ideal Opening Die Co., New York. At the time of his death Mr. Mullaney had consulting offices in New York.

He became a member of the Society in 1901. He died suddenly in the early part of June 1918 in Redbank, Cal.

STEPHEN MINOT PITMAN

Stephen M. Pitman, vice-president of the Narragansett Mutual Fire Insurance Co., died at his home in Providence, R. I., on December 17, 1918.

Mr. Pitman was born in Boston, Mass., on July 19, 1850, and was educated in the public schools of that city. For a short period he attended Brown University, later going to Tufts College, where he received the degree of Ph.B. in 1869. Following his graduation from Tufts Mr. Pitman entered the Harvard School of Mining, receiving the degree of Mining Engineer in 1874, and afterward went to Germany, where he pursued special studies in chemistry at the Universities of Heidelberg and Berlin. From 1877 to 1882 he was professor of chemistry at Tufts, at the close of that time becoming treasurer and general manager of the Butte Silver & Copper Mining Co., Butte, Mont. In 1886 he returned East as chemist and superintendent of the Valley Falls Co., Valley Falls, R. I. In 1888 he became general manager of the Copp Dyeing Co. He later became secretary of the Philadelphia Manufacturers' Mutual Fire Insurance Co., and was for a time connected with the Holmes Fibre Graphite Co., also of Philadelphia.

In 1894 he was elected secretary-treasurer of the Narragansett Mutual Fire Insurance Co., Providence, R. I., and remained in that capacity until he became vice-president, the office he was holding at the time of his death. He was also a director of the American Investment Co.

Mr. Pitman became an associate of the Society in 1892.

WILLIAM J. PLANK *

William J. Plank was born on November 1, 1887, in Jetmore, Kan. He was graduated from the University of Kansas in 1911 with the degree of A.B.; in 1913 he received his M.E. degree and shortly afterward was appointed through the Civil Service to the shops of the mechanical division of the Panama Canal Commission. His duties consisted of general drafting work dealing with construction equipment. He also acted as instructor in mechanical drawing to a class of about thirty apprentices. In April 1916 he was transferred to the planning department of the drafting room.

In the early part of 1918 he enlisted in the Air Service of the Army, and was assigned to the School of Military Aeronautics, Austin, Tex., and later transferred to the flying field at Sacramento, Cal.

Cadet Plank died on November 12, 1918, of pneumonia. He became a junior member of the Society in 1916.

GEORGE SUNTER POWER

George S. Power was born on May 17, 1870, in Brantford, Ont. He was graduated from the high school in Gaylord, Mich., and later took a five years' course at Cooper Union, New York, three of which were devoted to science and two to architecture.

Upon the completion of his high-school course he acted for three years as principal of a school in Duncan City, Mich. His next position was with the First National Bank of Duluth, Minn., as bookkeeper. About 1893 he left for New York City, where he became superintendent of the J. & J. Morrison Co., plas-

terers. In 1896 he became connected with the Witherspoon Plaster Mill, where his work consisted in the designing and building of labor-saving devices. In the following years he was associated with the Jackson Architectural Iron Works in designing and drafting; the Manhattan Concrete Co. in figuring and estimating; V. Dorne Sons, New York, as superintendent and estimator, and with the Rock Plaster Co., New York and Hoboken, as superintendent. In 1903 he was employed by the Robins Conveyor Belt Co. to design conveyor machinery; he also supervised the erection of a new plant for the company at Passaic, N. J. In 1903 he became identified with the U. S. Gypsum Co., Chicago, Ill., where his work consisted of designing and building new and remodeling old gypsum mills. From 1905 to 1916 Mr. Power was associated with the firm of Wickes Brothers, Saginaw Mich., where he held successively the positions of draftsman, designer of new machines, superintendent, and general manager of the rock-drill department. For the fourteen months, prior to his death he was with the Bayonne Steel Casting Co., Bayonne, N. J., as construction engineer and purchasing agent.

Mr. Power became a member of the Society in 1916. He died on January 14, 1918.

HENRY GEORGE PULSCHEN

Henry G. Pulschen was born in February, 1891, in New York City and attended the public schools there, being graduated from Cooper Union in 1908 and later from Pratt Institute.

From 1905 to 1907 he worked as machine apprentice with Schneider Brothers, Jersey City. His next position was with H. Crocheron, New York, where his duties dealt with patent-office drawings, machine designing, detailing and tracing. In 1910 he became associated with the Henry R. Worthington Co., Harrison, N. J., as designer, detailer and tracer of power-plant machinery, and the following year took a position with the Alberger Pump & Condenser Co., New York, as designer and checker of condensers, heaters, cooling towers, etc. In September 1917 he became connected with the J. G. White Engineering Corporation, New York, as designer, checker and squad leader. In about seven months he was transferred to the inspection department of the company, where he remained until his last illness.

Mr. Pulschen became a junior member of the Society in 1918. He died on December 24, 1918.

GEOFFREY LAWRENCE REID

Geoffrey L. Reid was born in Lawrence, Mass., on March 29, 1894. He was educated in the public schools of Lawrence and upon graduation from high school entered Massachusetts Institute of Technology, from which he was graduated in 1916 as a mechanical engineer.

His first position was with the General Electric Co., Lynn, Mass., in connection with cost work and estimating on Curtis steam turbines. He was next employed in the inspection department of the Associated Factory Mutual Co's., Boston, leaving there to enter the statistical department of the Stone & Webster Engineering Corporation, Boston. In December 1917 he enlisted in the U. S. Naval Aviation Corps and was assigned as an inspector of aeroplane motors and stationed at the Curtiss Aeroplane & Motor Corporation, Buffalo,

N. Y. In April 1918 he received his honorable discharge from the Army owing to ill health.

Mr. Reid died on December 23, 1918. He became a junior member of the Society in 1916.

CHARLES JAMES REILLY *

Charles James Reilly, Sergeant, Co. C., 21st Engineers, A. E. F., was killed in France, on September 1, 1918, by a bomb dropped from a German airplane, which, according to report, was flying low over the camp and bearing the Allies' colors.

Sergeant Reilly was born on September 10, 1887, in Louisville, Ky. He received his early education in the schools of that city and was graduated from the high school in 1905, when he entered Rose Polytechnic Institute, from which he received his B.S. degree in mechanical engineering in 1909. For three years he was connected with the Louisville & Nashville Railroad in Louisville, Ky., as a machinist in their locomotive-erecting shop. His next position was with the Vandalia Railroad, Terre Haute, Ind., as draftsman in the motive-power department, where he remained for a little over three years, resigning to become connected with the U. S. Division of Valuation of the Interstate Commerce Committee as junior mechanical engineer, where his work dealt with the valuation of the mechanical property of railroads. In April 1916 he became assistant to the superintendent of the Sandusky Cement Co., Bay Ridge, Ohio, where he was employed at the time of his enlistment, July 1917. He was sent to Camp Grant, Ill., for training and in January 1918 went to France as a member of Co. C., 21st Engineers.

Sergeant Reilly became an associate-member of the Society in 1916.

GEORGE GUSTAV ROHLIG

George G. Rohlig was born on May 7, 1872, in Eisenach, Thuringia, Germany. He came to this country when about sixteen years of age and started work in the Botany Worsted Mills, Passaic, N. J., returning to Europe a few years later. He studied in technical universities at Winterthur and Zurich, Switzerland, and at the Royal Polytechnic High School, Stuttgart, Germany, receiving his engineering degree and thereafter being associated for a period with Leipziger Wollkammerie, Hoboken les Anvers, Succursale, on work having to do with textile machines. His drafting-room experience he gained while with Kammgarnspinnerei, Stoehr & Co., Plagwitz-Leipzig, Germany. He served his apprenticeship in the woolen and worsted mills of Belgium and England, thus laying the foundation of his great technical knowledge in the milling industry.

Upon his return to this country he again became associated with the Botany Worsted Mills as assistant superintendent in charge of the manufacturing. He also assisted in the various enlargements of the mills and since 1903 was director and general superintendent of the company, holding this position at the time of his death, October 29, 1918.

Mr. Rohlig became a member of the Society in 1909.

EDWIN H. ROUSSEAU

Edwin H. Rousseau was born in New Orleans, La., in September 1884. He was graduated from the Louisiana State University in 1905 with the degrees of B.S. and M.E. He also attended Tulane University.

His first position was with the Central Electric & Improvement Co., Inc., New Orleans, where he was located for about four years. In 1910 he became manager of the order department and draftsman for the John H. Murphy Iron Works, also in New Orleans. Three years later Mr. Rousseau became connected with Dibert, Bancroft & Ross Co., Ltd., as a designer on multiple-effect evaporators, vacuum pans and barometric condensers, resigning in 1916 to take a position with the Dyer Co., Cleveland, Ohio, having charge of the cane-sugar department, handling all engineering incidental to building cane-sugar factories, etc. In the early part of 1917 he became assistant engineer in the engineering department of the E. B. Badger & Sons Co., Boston, Mass., where he had charge of the engineering work connected with the building of complete industrial and chemical plants.

In October 1917 Mr. Rousseau accepted a position with the Birmingham Machine & Foundry Co., Birmingham, Ala., as chief engineer, which position he was holding at the time of his death, December 3, 1918.

Mr. Rousseau became a member of the Society in 1915. He was also a member of the Chemists' Club of New York and of the Civic Association of Birmingham.

WILLIAM PRESCOTT SARGENT

William P. Sargent was born in Stoneham, Mass., on September 9, 1878, and received his early education in the public schools of that city.

He was first employed in 1896 by Prentice Brothers, Worcester, Mass., manufacturers of machine tools, where he had charge of the stock room. His spare time he devoted to learning machine operation and machine fitting. His next position was with the Draper Machine Tool Company as draftsman. For a short while thereafter he was connected with the Lodge & Shipley Machine Tool Company, Cincinnati, as a designer of special machinery. In 1903 he was made special engineer for the Niles Tool Works, Hamilton, Ohio, where his work dealt with chemical and metallurgical research problems. He returned to the Pratt & Whitney Co. as assistant construction engineer in the design of the machine shop, foundry and power plant which were being erected. He was next made engineer in direct charge of the design and construction of the machine and forge shop of the Niles Tool Works. About 1907 Mr. Sargent became associated with the Barber-Colman Company, Rockford, Ill., as engineer to design and develop automatic textile machinery. From 1909 to 1915 he was engaged in the design and development of automatic machinery for handling periodicals, papers and paste, and in the design and construction for the Bureau of Chemistry of several graphic machines for recording impacts and stresses. He was associated also with the Curtis Publishing Company, Philadelphia, where he was interested in the reduction of labor costs in the mechanical processes involved in the publication of 5,000,000 magazine copies a month. During the years of 1915 and 1916 Mr. Sargent devoted his time to coördinating the facilities of more than twelve small shops whose production singly of gages, tools and ordnance parts would not

have been appreciable. Recently he was engaged in the construction of gages and interested in other work for the Frankford Arsenal.

Mr. Sargent became a member of the Society in 1909. He died on April 10, 1918.

CHARLES R. SEED *

Charles R. Seed, Lieutenant U. S. N. R. F., was born in April, 1876, in Lawrence, Mass. He was educated in the schools of that city, later receiving training aboard the Massachusetts Nautical Schoolship *Enterprise*, after which he served as an engineer for seven years on runs between Europe and America. From 1900 to 1902 he was chief engineer of the Utica Knitting Co., Utica, N. Y., leaving to become watch engineer of the Metropolitan Street Railway Co., New York, where he was located for two years. In 1904 he took a position with the Blackstone Manufacturing Co., Blackstone, Mass., as chief engineer. He was next associated with the Rockingham County Light & Power Co., Portsmouth, N. H., as superintendent of power. In 1911 he became superintendent of power for the Worcester Electric Light Co., Worcester, Mass.

During the Spanish American War Lieut. Seed served as junior engineer aboard the *St. Louis* and when the United States declared war against Germany, he was granted a leave of absence by the Worcester Company and at once offered his services to the Government. He was commissioned an ensign and assigned to the Boston Navy Yard. After a short while he was ordered overseas to do patrol duty in the war zone off the coast of France in the U. S. S. *Wavika*. He was promoted to the rank of lieutenant while overseas. Upon his return to the United States he was assigned to the Fore River Shipyard and actively employed in connection with the fitting out of motive power for sea duty.

Lieutenant Seed died suddenly of pneumonia, in Worcester, on October 8, 1918. He was a member of the National Association of Stationary Engineers. He became a member of the Society in 1914.

HORACE MILLIKEN SMITH

Horace M. Smith was born on November 1, 1880, in Terre Haute, Ind., and received his early education there. He was graduated from St. Albans Military Academy and later attended the Massachusetts Institute of Technology. He served an apprenticeship with the Niles Tools Works Co., Hamilton, Ohio, as draftsman and also with the American Soda Fountain Co. in the same capacity. In 1904 he became associated with the Liquid Carbonic Co., Chicago, Ill., as a designer and traveling erecting engineer and was advanced rapidly until in 1908 he was given full charge of the iron foundry, the brass foundry and the machine shops. At the time of his death he was chief engineer of the company.

Mr. Smith was an authority on all matters pertaining to the carbonated-drink and bottling industry and the inventor of several devices which have resulted in a practical revolution of that business.

Mr. Smith became a member of the Society in 1913. He died on November 12, 1918.

ROY BROOKS SMITH

Roy Brooks Smith was born in March, 1882, in Uhrichsville, Ohio. He was educated in the schools there and later attended Ohio State University, receiving his M.E. degree in 1904. During his vacation periods he served an apprenticeship with the Pennsylvania Lines West, and upon graduation became connected with the same company on locomotive road tests.

In 1906 he was made assistant engine-house foreman and assigned to Logansport, Ind. In about another year he was promoted to assistant electrical engineer, S. W. S., and was located at Columbus, Ohio. In 1908 he became general foreman of the C. L. & N. Railway, Cincinnati, working there for about two years when he was promoted to the position of assistant master mechanic and returned to Columbus. Early in the spring of 1911 he became assistant motive-power inspector and shortly afterward motive-power inspector, in charge of the design and layout of power plants, coaling stations, washout systems, etc., the making up of specifications, tests of material, apparatus and equipment. Just previous to his death, October 19, 1918, he was made assistant electrical engineer.

Mr. Smith, though physically unable to enter the Service, was enrolled in the U. S. Public Service Reserve, Washington, D. C., and worked arduously in the local recruiting office of the Officers' Training Camp. He also had charge of the Columbus Community War Chest subscriptions in the office of the superintendent of motive power and general superintendent of the company.

Mr. Smith became a junior member of the Society in 1905 and was elected to full membership in 1912.

WILLIAM WARREN SMITH

William W. Smith was born in Toronto, Canada, on September 9, 1876. He was educated in the public schools of Michigan and in Michigan Agricultural College, taking the mechanical-engineering course. Later he attended Purdue University, where he took special work in mechanics.

He obtained his shop experience with the Welded Steel Barrel Company, Detroit, Mich., where for about a year and a half he was draftsman and inspector. He spent two years with the American Car and Foundry Company, Detroit and St. Louis, as draftsman, estimator and finally as chief draftsman. His next position was with the Standard Steel Car Company, Pittsburgh, as assistant construction engineer, where he remained for about a year, leaving to become assistant manager with the Mexican Car and Foundry Company, Mexico City. He remained in Mexico, transferring his business connections to the National Iron and Steel Works as superintendent and mechanical engineer in charge of design for miscellaneous machine and structural-steel work. About 1916 Mr. Smith became associated with Dodwell & Co., New York, as foreign representative with Behn Brothers, San Juan, Porto Rico. In February 1918 he joined the sales force of the Allis-Chalmers Manufacturing Company, expecting later to be transferred to sales work in South America, with which country he was especially familiar.

Mr. Smith became a member of the Society in 1909. He died in Milwaukee, Wis., on April 1, 1918.

FREDERICK W. SNYDER

Frederick W. Snyder was born on June 18, 1884, in Philadelphia, Pa. He was educated in the public schools and later attended the Williamson Free School of Mechanical Trades, from which he was graduated in 1904.

Upon his graduation he was employed as machinist in the Frankford Arsenal, Philadelphia, where he remained for over a year and a half. His next position was with the Buckhorn Portland Cement Co. as draftsman, but after a brief period in this capacity he was appointed assistant mechanical engineer of the plant. In 1908 he became associated with the Baldwin Locomotive Works, Philadelphia, Pa. His work there was in the drafting room and consisted of detailing and designing electric mine locomotives. After a year and a half he resigned to take a position with the Miller Lock Co., Frankford, Philadelphia, Pa., where he designed tool-room jigs and fixtures, blanking and bending dies, etc. In April 1910 he became an instructor in the Williamson Free School of Mechanical Trades, Delaware County, Pa. At the time of his death he had charge of the classes in strength of materials and in machine-shop practice.

Mr. Snyder became an associate-member of the Society in 1916. He died on January 29, 1918.

JOHN PORTERFIELD SPARROW

John Porterfield Sparrow, for many years a member of the Society, died at his home in Flatbush, Brooklyn, on March 18, 1918. He was born in Portland, Me., on March 17, 1860.

Mr. Sparrow was an engineer by inheritance and education, his father, John Sparrow, being well known in the engineering field. His early education was obtained in the public schools of Portland, but this was largely supplemented by his father's teachings in physics, chemistry and engineering.

In 1879, being interested in sugar manufacture, Mr. Sparrow was taken to Europe by his father to study the industry, and while there visited all of the larger engineering works. In 1880 he entered the Portland Company's locomotive and marine-engine works as an apprentice. He served his apprenticeship and became a toolmaker and erector for that company, leaving them in 1888 to work for the Sprague Electric Company. During the next two years he acted as superintendent for the Sprague Electric Company, in charge of construction of electric railways in the various parts of the country. In 1890 he went to New Orleans for the New Orleans Electric Company on construction work. In 1892 he joined the construction staff of the Edison General Electric Company and was employed in building lighting and power plants for them and the Canadian General Electric Company until 1895. In 1895 he joined the staff of the construction department of the Edison Electric Illuminating Company of New York, and in 1898 became superintendent of construction, having charge of all of the construction, which included the new Waterside Station, at that time the largest and most important construction of its kind which had been attempted. In 1906 he became chief engineer of The New York Edison Company in charge of construction and operation, the position he held at the time of his death.

Mr. Sparrow became a member of the Society in 1898 and was an active member, serving on various committees. At the time of his death he was Chairman of the Committee on Standardization of Flanges and Pipe Fittings, and had

just finished the completed report on that subject. On February 1, 1918, he was appointed Chairman of the Advisory Board of the Power Test Committee. His work along these lines was particularly valuable, as his long experience, trained judgment and personal influence insured the reconcilation of conflicting interests.

In the Association of Edison Illuminating Companies he was a member of the Committee on Steam Plants from 1906 up to the present time, and was chairman in 1910, 1912 and 1913. In this work his most valuable contributions were those in connection with coal testing and burning. Before the Edison Association he presented a number of papers on boiler-plant problems.

In the National Electric Light Association he was a member of the Committee on Prime Movers for a number of years, and was a frequent contributor to the Question Box.

Shortly after the United States entered the war he made a number of tests for the Naval Consulting Board in connection with smoke abatement on ships as a protection against submarines.

Mr. Sparrow's hobbies were largely of an engineering character. In photography his work as an amateur rivaled many professionals, and he was one of the first to take up color photography. Microscopy, as a result of his early training, was always one of his chief aids and his work on the photomicrography of lamp filaments is well known. In later years he turned to metallography in connection with the ever-present subject of the corrosion of condenser tubes, and assisted in the settling of important questions of heat treatment in the manufacture of this material. His knowledge of physical science was fundamental and he was an adept in the mechanical handling and manipulation which is a necessity in research work of this kind.

GOLDWIN STARRETT

Goldwin Starrett was born on September 29, 1874, in Lawrence, Kan. He was graduated from the University of Michigan in 1894 with the degree of B.S. in mechanical engineering and spent the following four years in the office of D. H. Burnham, Chicago, Ill., architect, as architectural draftsman and assistant mechanical engineer. In 1898 he became superintendent and assistant manager in the New York office of the George A. Fuller Co., where he remained for about two years, leaving to take the position of secretary and assistant general manager of the Thompson-Starrett Co., New York. While with this firm he did a vast amount of mechanical work in the construction of commercial and office buildings. In 1904 he became vice-president of the E. B. Ellis Granite Co., of Northfield, Vt., which position he occupied for four years when he became the senior member of the architecural firm of Starrett & Van Vleck, designers of many large and important buildings in New York.

Mr. Starrett was a member of the American Institute of Architects and also of the Architectural League. He became a member of the Society in 1914. He died on May 9, 1918.

EDWIN A. STEVENS

Col. Edwin A. Stevens, member of the famous old American family which in Revolutionary days practically founded what we now know as the city of Hoboken, died on March 8, 1918, in Washington, D. C., where he was serving as a field officer of the Emergency Fleet Corporation.

He was born in Philadelphia on March 14, 1858, and attended St. Paul's School, Concord, N. H., later entering Princeton University, from which he was graduated in 1879 with the degree of A.B. In 1905 he was given the degree of Doctor of Engineering by the Stevens Institute of Technology, founded in 1868 by his father, Edwin A. Stevens.

He served as Park Commissioner and as Tax Commissioner of New Jersey and also on the commission which settled the long-standing boundary dispute between the states of New York and New Jersey. For some time he was also Commissioner of the New York and New Jersey Palisades Interstate Park. In 1880 he was made adjutant of the old Ninth Regiment of New Jersey, and later served on the staff of Governor Ludlow. His appointment as Colonel of the Second Regiment came still later, and he was commander of the regiment for six years. In 1911 he was appointed Commissioner of Public Roads by President Wilson when the latter was Governor of New Jersey. In 1914 he was reappointed by Governor James F. Fielder and served until 1917, when the laws were changed and the management of the road department was taken out of the hands of a commissioner and invested in a commission of eight members. A little later he was appointed a member of the State Highway Commission by Governor Edge.

Colonel Stevens designed the *Bergen*, the first screw-propeller ferryboat. This vessel is still in commission and operates between Hoboken and New York. That invention marked a signal departure in the construction of such vessels and one which proved so satisfactory that all other ferry lines adopted the patent. He had many other inventions of a mechanical nature to his credit. He was president of the Hoboken Ferry Company until 1896, when it was taken over by other interests, later being acquired by the Lackawanna Railroad.

Colonel Stevens was a member of the Society of Naval Architects and Marine Engineers and of the Institute of Naval Architects in Great Britain. He became a life member of the Society in 1889.

MATTHEW ANDEN SYKES

Matthew A. Sykes was born on March 26, 1865, in Wallingford, Pa. His early education he obtained in the schools of Delaware County, Pa. Later he took several courses in the evening schools of Philadelphia and was graduated from The Franklin Institute, his course there being in mechanical drawing.

From 1880 to 1890 Mr. Sykes worked with the Baldwin Locomotive Works, Philadelphia, where he first served his apprenticeship and was advanced to the position of contractor and then of foreman on production. For a short period in 1890 he was connected with the Midvale Steel Co., Philadelphia, as foreman in charge of the production work. He left this firm to take a position with Goodell & Waters Co., manufacturers of woodworking machinery in Philadelphia, where he directed the designing and making of tools and planned the work throughout the shop. In 1892 he became foreman with Bement, Miles Co., Philadelphia, and directed the building of special machinery. His next position was with the Sprague Electric Elevator Co., New York, as superintendent of their New York and Watsessing, N. J., plants and of construction on the installation of electric elevators. In 1896 he became superintendent of construction in the New York office of Morse, Williams & Co., Philadelphia, and installed all kinds of hydraulic, electric and belt-power elevators in the metropolitan district. The year 1897 to

1898 he spent with the Metropolitan Electrical Construction Co., on the installation of electric elevators in New York City. In 1898 he became associated with the Otis Elevator Co., New York, as assistant superintendent of construction, installing hydraulic and electric elevators, and for six months was superintendent of construction at the Pittsburgh office of the company. Mr. Sykes left the Otis Elevator Co. in 1905 to become superintendent of construction with the Standard Plunger Elevator Co., Worcester, Mass., of their New York and Toronto offices on the installation of plunger and electric elevators. After six years with this company he was for two years superintendent of construction of the Gurney Elevator Co., and for about a year with the Westinghouse Co., Schenectady, N. Y., as superintendent of their plant manufacturing agricultural machinery, grain separators, steam tractors, locomotive stokers, etc. In 1915 he accepted a position with the Remington Arms Co., Eddystone, Pa., as superintendent of the division on production work of British rifles. At the time of his death he was superintendent of the erection shop of the Baldwin Locomotive Works, Eddystone, Pa.

Mr. Sykes became a member of the Society in 1917. He died on March 10, 1918.

FLOYD G. TEN BROECK

Floyd G. Ten Broeck was born in Elmira, N. Y., on August 28, 1872, and received his early education in that city. Later he attended Cornell University and was graduated in 1895 with the degree of M.E. His first position was with the Osborn Engineering Co. and dealt with shop engineering. From 1897 to 1899 he was connected with Miliken Brothers and also with R. P. and J. H. Statts, where he obtained his drafting experience. In 1899 he became associated with Westinghouse, Church, Kerr & Co. in the design and erection of mills and power plants, leaving that firm to open private consulting offices in New York City in 1902. For the last sixteen years he was manager of the engineering department of the West Virginia Pulp & Paper Co., New York.

Mr. Ten Broeck became a member of the Society in 1903. He died on November 1, 1918.

DAVID TOWNSEND

David Townsend, a member of the Society since 1882, and vice-president during the years 1899 to 1901, died at his home in Philadelphia, Pa., on November 27, 1918.

Mr. Townsend was born on February 21, 1856, in Philadelphia, Pa. He was a graduate, class of '76, of the University of Pennsylvania, degree of B.S. In 1878 he was a special student at Stevens Institute of Technology, and assistant to Dr. R. H. Thurston and Prof. Albert H. Leeds. From 1878 to 1893 he was with the Bush Hill Iron Works, Philadelphia, specializing in rolls, rolling mills, steel and iron-works construction equipment. He first served his apprenticeship in machine shop, foundry and drawing room, later becoming general manager. In 1893 he became general manager of the Philadelphia Roll & Machine Co., building and operating their works. He was with this firm until 1898, when he went to Germany to the Krupp Works at Magdeburg to study the methods and construction of the Gruson revolving coast-defense turrets. Upon his return he designed, built and operated the Gruson Iron Works, Eddystone, Pa., as general

manager. In 1903 this property was sold to the Baldwin Locomotive Works, who have since occupied it for themselves and for the Remington Arms Co.

From 1903 to 1912 Mr. Townsend was engaged in private engineering practice, specializing in iron and steel foundries, roll and rolling-mill designs and general construction for iron and steel products. He became president of the Production Engineering Co. in Philadelphia in 1912, specializing in oil-burning apparatus of all kinds, holding this position up to the time of his death.

During the year 1916 Mr. Townsend was also manager of the Philadelphia plant of the Neidich Process Co. and the Calco Chemical Co., producing aniline dyes.

SAMUEL F. TRIPP

Samuel F. Tripp was born in New Bedford, Mass., on November 14, 1866. He was educated in the public schools of New Bedford and later attended the New York evening schools and the Polytechnic Institute of Brooklyn. He also took a course in the International Correspondence Schools of Scranton, Pa.

At the age of eighteen he accompanied his father on a trip to California and while there entered the employ of the Arctic Whale Oil Co., where he worked for two years. His next position was with the Corliss Steam Engine Co., Providence, R. I., as erecting engineer, where he had charge of the installation of engines in the plant of the Waterbury Electric Light Co., Waterbury, Conn., and of repair work on engines in many cities of Rhode Island and Massachusetts. He then entered the employ of the Jones & Laughlin Co., Pittsburgh, Pa., and had charge of the erecting of shafting, being employed for about two years in various mills throughout New England. He was reëmployed by the Corliss Co. and placed in charge of erecting boilers, handling the installation of boilers in Elizabeth, N. J., New York and Baltimore.

In 1891 Mr. Tripp became associated with the Third Avenue Railroad Co., New York, and was put in charge of the erecting of the engines at the Sixty-fifth Street and Bayard Street power stations. In 1901 when the motive power of the Third Avenue System was changed from cable to underground electric the cable power stations were shut down and he was transferred to the Ninety-sixth Street power station of the Metropolitan Street Railway Co. as engineer in charge. From April 1914 until the Ninety-sixth Street station was discontinued Mr. Tripp, in addition to his duties as engineer of that plant, was also employed to superintend mechanical construction work at the Seventy-fourth Street power station of the Interborough Rapid Transit Co., having charge of all mechanical equipment in connection with the 30,000-kw. turbines installed in that plant. At the time of his death, September 29, 1918, he was field engineer in charge of mechanical construction connected with the 60,000-kw. turbine now being constructed at Seventy-fourth Street.

Mr. Tripp was a member of the National Society of Stationary Engineers. He became an associate-member of the Society in 1915.

CLARENCE B. D. UNVERFERTH

Clarence B. D. Unverferth was born on October 10, 1884, in Dayton, Ohio. He was educated in the parochial schools and in St. Mary's College in Dayton, later taking a special course in hydraulic and steam engineering.

From 1902 to 1907 he was connected with the Platt Iron Works, Dayton, as draftsman on pumps, heaters, condensers and filter-press machinery. His next position was with the Dayton Hydraulic Machinery Co., as chief draftsman and designer on centrifugal pumps. He was with this company for three years, resigning to become designer and draftsman on paper-mill machinery and water wheels for the Dayton Globe Iron Works. In 1911 he became connected with the Ohmer Fare Register Co., Dayton, as tool designer, and the following year was with the Recording and Computing Machines Co., Dayton, as designer of tools and screw-machine cams. In 1913 he entered the office of the County Engineer of Montgomery County, Ohio, as chief draftsman and surveyor in charge of all drafting and field work. At the time of his death he was connected with the Aircraft Production Board at Dayton.

Mr. Unverferth died of pneumonia on November 10, 1918. He became an associate-member of the Society in 1918.

PHILIP WALLIS

Philip Wallis was graduated from the Stevens Institute of Technology in 1879. He was first employed by the Clark Bridge Co. as draftsman. His next position was as instructor in mechanical drawing at the Maryland Institute Night School of Design. In the latter part of 1880 he was made assistant in the testing department of the Chicago, Burlington & Quincy Railroad and the following year became engineer of tests in charge of the physical laboratory of that company. In 1886 he became connected with the Long Island Railroad Co. as superintendent of equipment.

Mr. Wallis became a member of the Society in 1886. He died on March 3, 1918.

GEORGE E. WHITEHEAD

George E. Whitehead was born on September 6, 1846, at Ashton-under-Lyne, Lancashire, England. He was brought to this country when but a child and was educated in the public schools of Providence, later taking a special course in mathematics at the Jenks Morey School of that city.

During the period of the Civil War Mr. Whitehead was employed by the Burnside Rifle Works Co., leaving at the close of the war to serve his apprenticeship as mechanic with the Brown & Sharpe Manufacturing Co., Providence, R. I., at the same time completing his studies in algebra, geometry and trigonometry. He was next employed by the Household Sewing Machine Co. as tool maker and die cutter. In 1874 he became associated with the Rhode Island Tool Co., as assistant superintendent and later became superintendent, serving in that capacity for thirty-one years.

Mr. Whitehead became a member of the Society in 1887. He died on March 4, 1918.

CHARLES SMITH WHITNEY

Charles S. Whitney was born on August 25, 1881, in North Attleboro, Mass. He received his early education in the public schools of Boston. His technical education he obtained through many years of intensive study by correspondence and through lectures.

He served an apprenticeship of two years with the Holtzer-Cabot Electrical Co., Brookline, Mass., as electrical machinist and draftsman. In 1899 he became assistant to the mechanical superintendent of the Massachusetts General Hospital, Boston. His next position was as construction foreman with the Elektron Manufacturing Co. In 1903 he became associated with the General Accident, Fire and Life Insurance Corporation as elevator inspector, and two years later became senior inspector. In 1912 he was appointed engineer in charge of inspection work and in 1914 became chief engineer in complete charge of all engineering work for the corporation. The following year he was made executive superintendent and at the time of his death, on October 31, 1918, was holding this position.

Mr. Whitney became an associate-member of the Society in 1916.

WALTER MARANTETTE WILHELM *

Capt. Walter M. Wilhelm was born in Defiance, Ohio, on November 13, 1884. He was graduated from the United States Military Academy at West Point, N. Y., in June 1906, and from the School of Ordnance Engineering, Sandy Hook Proving Ground in July 1909. In August of that year he became assistant and general superintendent at the Watervliet Arsenal, Watervliet, N. Y., the commanding officer being Col. W. W. Gibson. He was in charge of the operation of construction of field and coast guns, specializing in the subject of relining the latter type. He was also responsible for the installation of the Taylor system of manufacture at the Watervliet Arsenal. In 1913 he was transferred to Frankford Arsenal, Bridesburg, Philadelphia, where he was assistant to the officer in charge of the optical department dealing with the manufacture and design of seacoast instruments. Later he became assistant to the officer in charge and then himself officer in charge of the artillery department at Frankford, where his duties gave him charge of the manufacture and design of shrapnel, shell, time and detonating fuses, hand grenades, rifle-grenades, etc., used in the Army and Navy. In November 1915 he resigned from the Army to become vice-president and general manager of the Eddystone Ammunition Corporation, Eddystone, Pa., where he had full charge of the manufacture of 2,500,000 complete rounds of Russian shrapnel. He was holding this position at the time of his death, October 3, 1918.

Captain Wilhelm became a member of the Society in 1916.

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1 **Names of authors** and discussers, also those of deceased members preceding an obituary notice, **are in caps and** small caps. A discusser is distinguished from the author of a paper by (*D*), **placed after the** name of the paper.

2 **Titles of papers,** where placed after the name of the author, and appearing in their exact form, **are in italics.** Papers are indexed not under their titles but under their subject-matter.

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